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Development of a mathematical model to relate actual versus theoretical needs of PVC paste

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"Conviene a tutti, capisci? Conviene a tutti far credere pazzi certuni, per avere la scusa di tenerli chiusi. Sai perché? Perché non si resiste a sentirli parlare. […] Non si può mica credere a quello che dicono i pazzi! Eppure, si stanno ad ascoltare così, con gli occhi sbarrati dallo spavento. Perché? […] Perché trovarsi davanti a un pazzo sapete che significa? Trovarsi davanti a uno che vi scrolla dalle fondamenta tutto quanto avete costruito in voi, attorno a voi, la logica, la logica di tutte le vostre costruzioni!"

Luigi Pirandello da Enrico IV

Development of a model to relate actual versus theoretical needs of PVC paste

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Abstract

The production of industrial vinyl-paste is often considered an extremely complicated procedure. The intricate nature of this process causes difficulties in paste production scheduling due to the multiple variables that can each influence the final quality of the paste and the produced quantity. Despite having production plans in place to determine the right quantity of paste needed the accuracy of these estimates often falls short. This has resulted in companies being unable to cope with the demand and required amount of finished products. The waste and loss of materials experienced throughout the process lifecycle has been identified as the main contributor of these inefficiencies.

The present work aims to achieve two main objectives.

- Provide a mathematical model to help reduce the disparity between required and actual amounts of PVC paste.
- Develop a methodology to investigate causes of loss and waste through the production line as a general approach that can be adopted by any process within the industry.

The proposed model includes any significant variables responsible for deviation between theoretical and obtained quantity of vinyl-paste and is built on average values from historical data rather than instances of isolated cases. The error committed by the model and estimated through validation is around + 1%. Furthermore potential causes of waste are also addressed with a generic solution for inefficiency minimization proposed. A cost saving of up to 55% can be achieved according to the suggestions developed.

Abstract

La produzione industrial di paste viniliche è spesso considerata una procedura estremamente complessa. L'intricata natura di questo processo causa difficoltà nella programmazione della produzione delle paste plastiche, a causa delle innumerevoli variabili che possono influenzarne la qualità e la quantità prodotta. Anche se esistono piani produttivi per determinare la giusta quantità di materiale plastico da introdurre in input al processo produttivo, la loro accuratezza si rivela spesso essere molto bassa. Questo è risultato nell'incapacità da parte di alcune imprese di far fronte alla domanda finale del cliente e quindi di soddisfare quantità richiesta di prodotto finito. Sprechi e perdite di materiale lungo la linea, sono stati identificati come i principali responsabili di queste inefficienze.

Il progetto ha due obiettivi principali.

- Fornire un modello matematico che aiuti l'azienda a ridurre la disparità tra quantità richiesta e prodotta di pasta PVC.
- Sviluppare una metodologia che indaghi le cause di perdite di massa e inefficienze lungo la linea produttiva,
  come un approccio generale che possa essere adottato per qualsiasi processo.

Il modello proposto include ogni principale variabile responsabile della deviazione tra quantità teorica e ottenuta di pasta vinilica ed è costruito su valori medi calcolati sulla base di dati storici anziché su risultati di casi isolati. L'errore commesso del modello e stimato tramite un processo di validazione è circa + 1%. Inoltre sono state individuate cause potenziali di inefficienze e proposte soluzioni. Una riduzione dei costi fino al 55% può essere raggiunta tramite i suggerimenti sviluppati.

ACKNOWLEDGEMENTS

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This project worth for me more than a working experience.

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PVC	Polyvinyl chloride
IUPAC	International Union of Pure and Applied Chemistry
UV	Ultraviolet
Pa	Pascal
D_1	Small mixer (capacity 1500 - 3300 Kg)
D_2	Big mixer (capacity 200 – 700 Kg)
F	Foam Paste
C	Compact Paste
N	Nominal quantity of paste in input
I	Real quantity in Input to the mixer
O	Real quantity in Output from the mixer

1 INTRODUCTION

1.1 PVC Industry

For more than 50 years, PVC has been very successful throughout the world. Today, this versatile material is one of the most important plastic materials recognised internationally and proven on the market.
PVC has distinguished itself especially with its wide range of applications. PVC products are often cost-effective in terms of purchasing and maintenance. At the same time, they contribute more and more to sustainable development throughout their entire life cycle: this occurs by means of state-of-the-art manufacturing and production methods, the responsible use of energy and resources, cost-effective manufacturing and processing, as well as numerous recovery possibilities. This progress has led to a continuous increase in the demand for this plastic material. Moreover, through cost-effective PVC products, society saves money which can be spent on sound ecological and social investments.
PVC is one of the most important plastic materials in Europe and is in a class of its own worldwide. The PVC industry has achieved enormous economic importance through its extremely wide range of high quality products. The prognosis shows continued growth. PVC processing1 in Europe is at 4.9 million tonnes per year. Thus, PVC is one of the most important plastic materials after the polyolefins polypropylene and polyethylene, which have a 50% of the market share. The outstanding importance of PVC is documented in the chart on the right.

Worldwide, PVC is in a class of its own. Vinyl is in third place among distributed plastic materials. All predictions point to- wards the
continued growth of plastic materials2 as well as of PVC (see chart on page 4). PVC processing has increased comparatively slower in Europe. A high degree of market penetration has already been achieved in this sector. Nevertheless, growth has been

registered even at this high level: this is an indication of the major importance of this high-performance plastic material.

The concentration of suppliers varies according to continent. In China, a large number of small suppliers dominate. In North America, on the other hand, five major manufacturers control 88% of the market. In Western Europe, the five largest providers supply 64% of PVC. Taking into consideration the capacities of the largest manufacturers worldwide in 2009, Shin-Etsu is at the top, followed by Formosa Plastics, Solvay, and LG Chemicals. In terms of PVC specialities for paste processing, the situation is somewhat different. Here, the Europeans claim the top three positions,3 held by Vinnolit, Vestolit, and Solvay/SolVin.

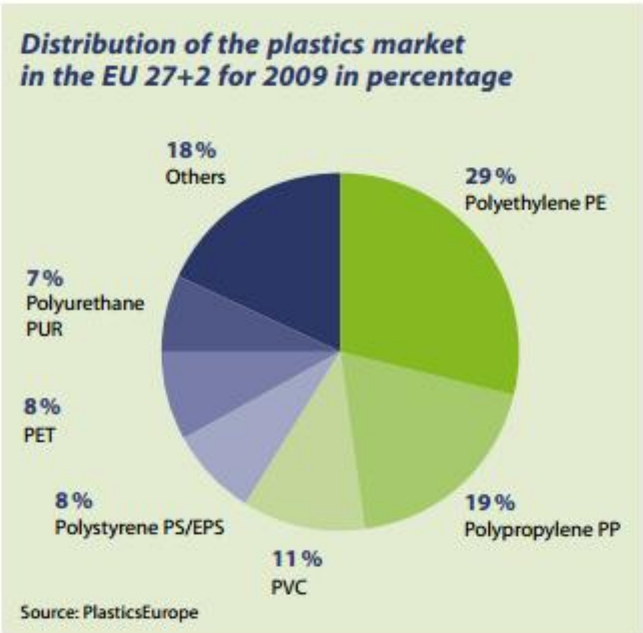


Figure 1-1 Plastics market share

The European PVC industry has consistently improved its manufacturing processes in re- cent years. This is especially true for formulas. Thus, there have been considerable changes in the use of stabilisers and plasticisers.

Crude oil/natural gas and rock salt are the starting products for PVC manufacturing. Ethylene is the result of crude oil in the intermediate stage of naphtha through thermal “cracking”. Chlorine, on the other hand, is produced from rock salt through chloralkali electrolysis. For this purpose the modern, energy- saving membrane process is commonly used today. Sodium
hydroxide and hydrogen are thereby produced as important by-products. In turn, they are the raw materials for many other syntheses. Vinyl chloride (VC) is produced from ethylene and chlorine at a ratio of 43% to 57%. VC is the monomeric building block of PVC. The transformation of VC to PVC takes place through various technological processes.
PVC products are derived from a white, odourless powder which is mixed with additives for the further processing of semi-finished and finished products. Such admixtures are not only found in practically all plastics, but also in materials such as glass, steel, concrete, etc.
basically, the following additives are used:

- stabilisers and co-stabilisers
- lubricants
- polymer agents to improve tenacity, heat and form stability and processing performance
- fillers
- pigments
- plasticisers

Additives facilitate processing and simultaneously determine the properties of end products. The choice of additives depends on processing procedures and demands on the finished products. Depending on the choice of additives, PVC as a raw material is developed into sturdy, thick-walled pipes for drinking water or extremely thin, flexible film for packaging fresh meat. Additives thereby provide a wide range of product properties.

PVC can be processed into various products in a number of ways. The range extends from heat insulating, energy saving windows to sturdy pipes and easy-to-clean floor coverings. Approximately seventy percent of PVC materials are used in the building sector, many of which are long-life products.

PVC is one of the few polymers which can be processed thermoplastically and by means of pastes.14 Thermoplastic pro- cesses take place primarily on extruders or so-called screw presses. The final products are pipes, profiles, sheets, tubes, and cables.15 Film and floor coverings are created by means of calenders (rolling mills). Fittings and casings are produced in the injection moulding process and hollow bodies by blow moulding. Emulsion and micro-suspension PVC is applied as a paste to various soft PVC products such as tarpaulins, flooring, coverings, and artificial leather. As an alternative, rotation moulding is used to shape dolls and balls.

PVC can be used in numerous products due to its outstanding properties and therefore is an integral part of our lives. In Germany, approximately 70% of all PVC applications are in- tended for the construction sector. In particular, this includes window profiles, pipes, floor coverings, and roofing membranes. PVC windows are weather resistant, durable, easy to clean, economical, and recyclable at the end of their life cycles. Sturdy pipes made of rigid PVC transport valuable drinking water, drain roofs, and dispose of sewage water. They can be easily, safely, and economically installed by means of structural and civil engineering. Building products made of PVC are distinguished

especially by their longevity: this is a decisive criterion for selecting the appropriate material.

In the packaging sector PVC is found in special applications such as blister packs, adhesive tapes, hollow bodies, and cups. Cables and wires with an insulation or coating made of soft PVC play a decisive role in the smooth

operations of our daily lives in terms of energy supply, control functions, and communications. Protective undercoating, interior panelling, and cable harnesses inside vehicles and under the bonnet play an important role in the automotive sector. In addition, medical products such as blood bags or tubes, office articles, garden equipment and furniture, and tarpaulins are indispensable. These examples alone demonstrate the versatile possibilities of applications for PVC.

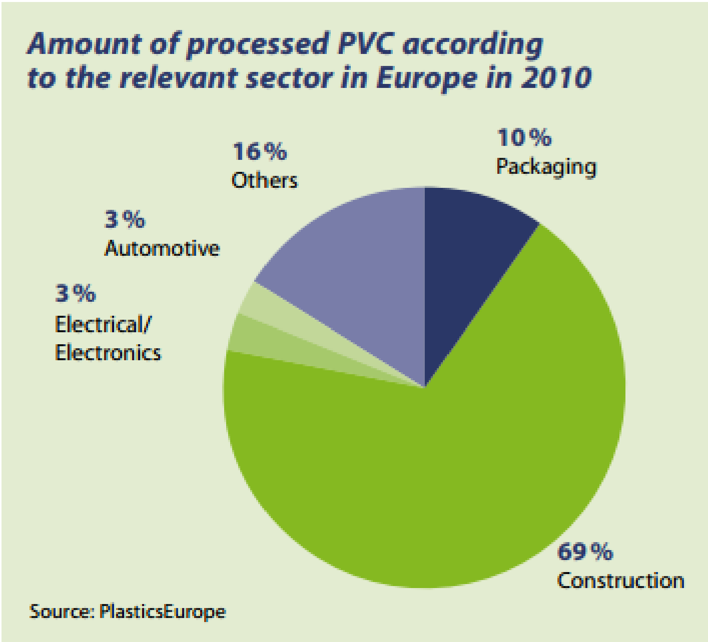


Figure 1-2 PVC usage

1.2 The Company

1.2.1 TMG Group

Figure 1-3TMG Automotive

Founded in 1937 under the name Fábrica de Fiação e Tecidos do Vale de Manuel Gonçalves, and changed to a anonymous society in 1965, Têxtil Manuel Gonçalves SA is the domestic market leader in the textile sector.

Today TMG covers the entire span of textile activities, ranging from spinning to distribution and including knitting, weaving, finishing and manufacturing. The business currently occupies a total area of 475,517 m2 of which 221,814 m2 are buildings.

Following restructuring undertaken in 2006, the TMG Group is now organised into strategic business areas which, although independent, endeavour to create synergies and thereby increase efficiency and competitiveness.

As a result of a diversification strategy initiated in 1985, the TMG Group owns other businesses and holds significant interests in other activities, namely:

• SPE – an electricity and heat generation company.

• HeliPortugal – founded in 1982, the oldest helicopter company in Portugal.

• Caves Transmontanas – a wine-producing company that is dedicated to the production and distribution of Vértice sparkling and mature wines.

• EFACEC – acquisition of joint control (with Grupo Mello) of the capital of the largest Portuguese electronics and electro-mechanical group.

• Founding partner of Millenium BCP, the largest private banking institution in Portugal.

• Lightning Bolt – the group's first incursion into the field of distribution, with a commercial operating licence for the charismatic surfing brand.

Drawing on its 70 years of experience, TMG meets the most demanding market expectations by means of versatility, innovation, excellent manufacturing performances and the flexibility of its industrial structure.

The philosophy of its founder, firmly based on the belief that technology and quality go hand in hand, has ensured systematic investment in cutting-edge technology for the company's manufacturing, control and management equipment. The fundamental considerations guiding TMG's management policies are visionary decision making, optimization of resources, seeking out new communication platforms, updating technologies and processes and maintaining respect for nature and for the workplace, all directed towards achieving the objectives of creating high-quality solutions for its customers.

The business areas of TMG Group are Fabrics, Decor, Finishing and Automotive.

TMG Fabrics aims to be a European leading supplier of shirting and outwear fabrics, using natural fibres with innovative designs and finishes.

TMG Decor wants to be the European leader of upholstery and decorative fabrics using natural fibres and unique finishing's.

TMG Finishing AT, can provide services for dyeing and finishing fabrics and yarns, for costumer outside the TMG Group. It elaborated technical frameworks that allow to develop partnerships with their clients so that they can respond to their needs and provide innovative solutions on both an aesthetic and technical level. The unit can provide a dyeing and finishing service for fabrics and yarns "yarn dyed" and "piece dyed" in a wide range of weights and raw materials for use in fashion clothing, work clothing, uniforms (career wear) and technical uses.

The project in analysis has been carried out in the fourth business unit of TMG Group: TMG Automotive. The department situated in Guimarães , in the north of Portugal. The Company is a manufacturer of plastic-coated foils and different synthetic coverings, used for vehicle interior trimmings. TMG Automotive is a member of The European Automotive Trim Suppliers Association. EATS is an international non-profit making association which represents the European automotive trim supplying industry. The association, founded in 1997, comprises at present eight member companies whose combined processing capacity represents a large proportion of the European automotive trim supplying market.

1.2.2 The products

TMG Automotive manufactures different types of synthetics coverings, mainly used in Automotive sector for interior vehicles trimmings, for istance door panels, dash boards, columns and central consoles among many other applications. The range of the products is quite broad, the coverings differ from

each other in chemical composition, colours, dimensions, shapes and treatments.

Whichever of those variable is been required from the customer, the starting point for the production process is always the same : plastisols pastes Figure 1-4.

In the present work, plastisols are commonly referred to as “vinyl-pastes” or simply “PVC-pastes”. A plastisol is a suspension of PVC particles in plasticizer, for further transformation into a flexible PVC foil, used for automotive interior trim applications.

Figure 1-4 PVC Paste Non-coloured

According to the International Union of Pure and Applied Chemistry (IUPAC), a plasticizer is a substance or material that once incorporated in a plastic, increases its flexibility, workability or distensibility. A plasticizer may reduce the melt viscosity and the glass transition temperature **Errore. L'origine riferimento non è stata trovata.**

To avoid end-product performance failures in terms of resistance to aging, retention of elongation after aging, fatigue after repeated flexing, abrasion resistance, UV-resistance, plasticizer extraction by oils or fats, stress-cracking and many others, the plastisols need to be compounded with additional additives. In order to achieve the needed flexibility of the end-products for automotive interior trimming, the plastisol formulation needs to be relatively high plasticized. Therefore in such plastisol recipes, the amount of plasticizer is always above 30 wt% of composition. Typical amounts of plasticizer are varying between 30 and 45 wt%. The second component of such plastisols added in high quantity, is the PVC resin itself. Concentrations ranging from 30 to 60 wt% of composition are usual for PVC resins. The additives are added in small amount, generally always under 7 wt%. Furthermore, pigments are usually added to plastisols in the same scale of the additive concentration.

A plastisol is a solvent free viscous mixture, with viscosity values ranging from 1000 to 30 000 Pa. The viscosity changes according to the recipe of the paste. Vinyl-pastes can either be formulated to produce monolithic compact foils or foamed foils. The first ones are simply called “compact-pastes” and the second ones are called “foam-pastes”. Foam pastes are usually higher viscous than compact pastes.

The foils can be impressed and lacked depending on customer requests, and cut in different dimensions. They are finally sold in rolls.

1.2.3 Processes

The schematized description of the production process for plastisol pastes, is given in Figure 1-5.

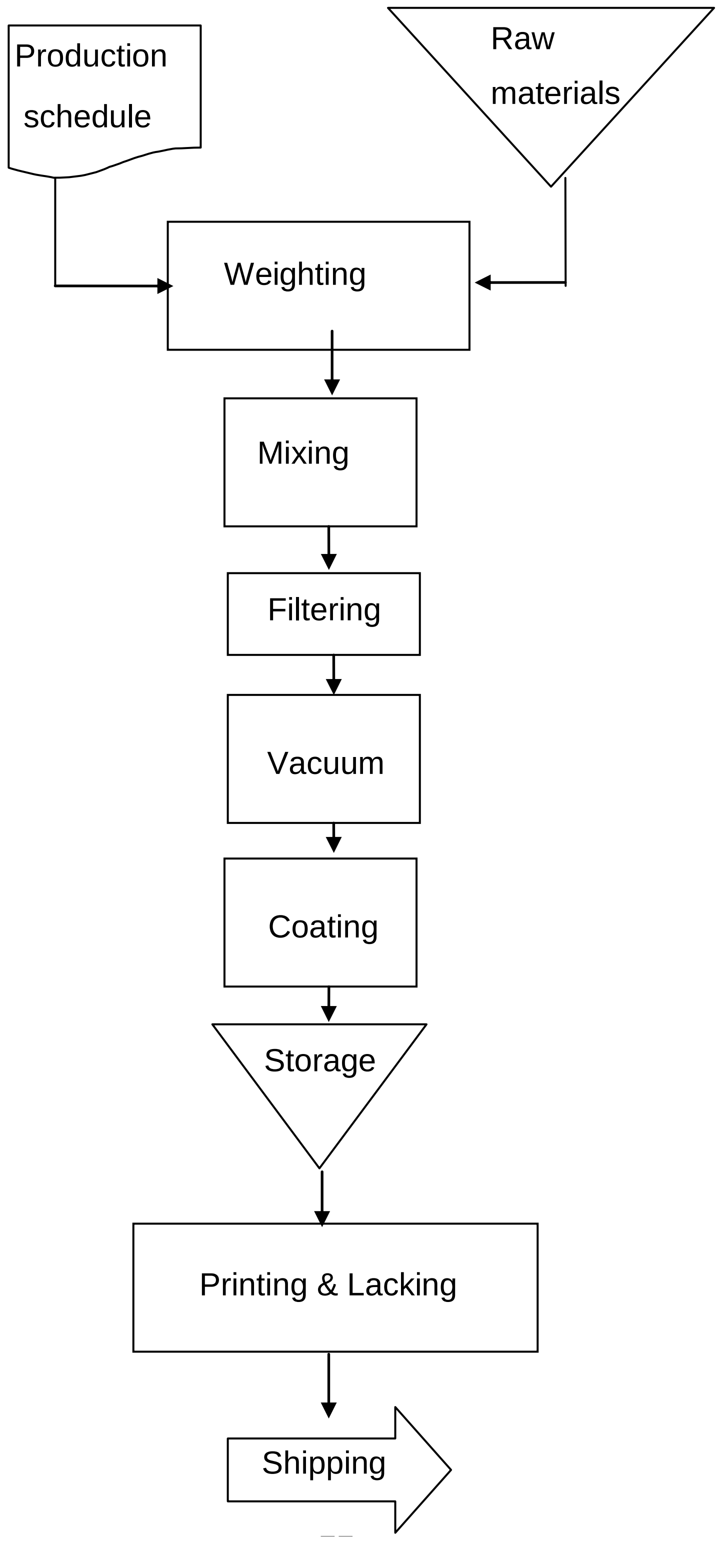


Figure 1-5 Process flow chart

The flow chart represents the usual production process of PVC pastes, in TMG Automotive plant.

The production department schedules the production (mainly on a weekly basis) according to the MPS that receives from the Logistics department. The raw materials (e.g. PVC in powder, plastisols, oils, pigments...) are stored inside the plant and given in input to the line through several pumps that pull the raw materials into the mixer after the required weight is reached. In other words, the pumps that connect the silos in which raw materials are stored with mixing units, are connected electronically to scales. Whenever the required amount of materials has been pull into the mixers, the pump stops. We will see in more details this mechanism and the potential problems related. After mixing, the pastes are filtered in order to remove dust or different deposits from the paste, a vacuum process will remove any trace of air particles instead.

The final vessel of pastes are now transferred from the so called “kitchen” to a second room, which contains the coating machine. Here the pastes are spread in foils and basically cooked, in order to achieve the right thickness and texture.

Usually one PVC foil is made by at least three layers. The one on the bottom is usually a non-colour paste, while the other two external layers give to the final product the right colour.

The coating machine is a huge machine, really big in dimensions and represents the real bottleneck of the Company. One coating machine can be long around 100mt and it can process at the same time two different types of pastes at the same time. Whenever the production changes paste in colour or composition, the machine has to be cleaned, therefore the production stops for minimum 12 hours and around 50% of paste is through away. It is absolutely important that each batch of paste is processed in a perfectly cleaned machines, any trace of previous batches must be removed from the pipes to maintain a high quality of the final product.

The foils of paste are then rolled and kept into an internal storage ready to be shipped or further processed in printing and lacking machine, depending on the final product. The printing machine imprints the required ribs of the leather, while the lacking machine spreads a shiny layer.

The final products are stored and finally submitted to quality checking.

The project does not cover the whole production process. It is limited to the first activities of the process that are carried out in the so called “kitchen”:

- Mixing process
- Filtering process
- Vacuum process

The limits of the projects are give as the main constraint is time and process criticality.

The Company has in fact identified the “kitchen” as the main responsible for losses and wastes through the line, therefore the project has been focused just on three process.

The usual paste routing for plastisol pastes is given in Figure 1-6.

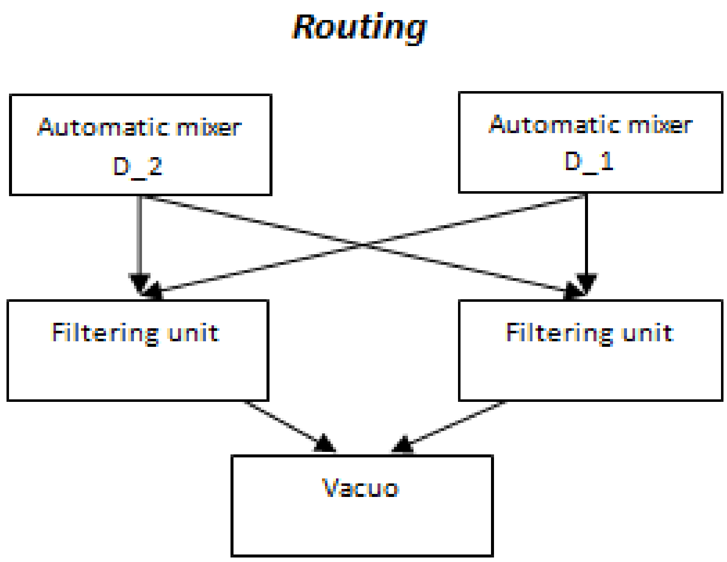


Figure 1-6 PVC production process

The vinyl-paste to be carried from one operation to another, is transported into steel vessels. Those vessels are cylindrical recipients over rolls, with capacities ranging from 200 to 700kg, depending on the dimensions Figure 1-7. Each vessel is marked with an adhesive, reporting paste reference, weight, viscosity, batch and date. A coloured sticker is then added in order to take record of quality inspections.

Figure 1-7 Vessels

1.2.3.1 Mixing process

The production of plastisols is not a chemical process. It is a physical mixing process, where solid PVC resins, combined with either solid or liquid additives, are stirred into a liquid plasticizer.

Mixing at industrial scale is done in batches, using automatic stirring mixers. It's a physical mixing process, absolutely free of chemical reaction. Heat exchange and changes in viscosity are of concern, but in a controlled way, since there is a temperature control that avoids severe changes in these two paste characteristics, maintaining the overall quality of the produced plastisol.

The mixing process can be done in fully automatic mixers or in manual controlled mixing units. Industrial quantities of plastisols are produced in automatic stirring mixers controlled by computer systems. In this case the raw materials are mixed according to specific mixer programs. The raw materials are weighted with automatic scales or dosed with volumetric pumps according to the mixer program.

In fully automatic controlled mixer, the plastisol is usually in a semi-closed system. In some mixing steps the system is opened, for instance to take air from outside, during the addition of the raw materials in order to avoid any pressure peak. When no raw material has to be added, the mixer program can run in a closed system. A representation of closed system mixer is given in Figure 1-8.

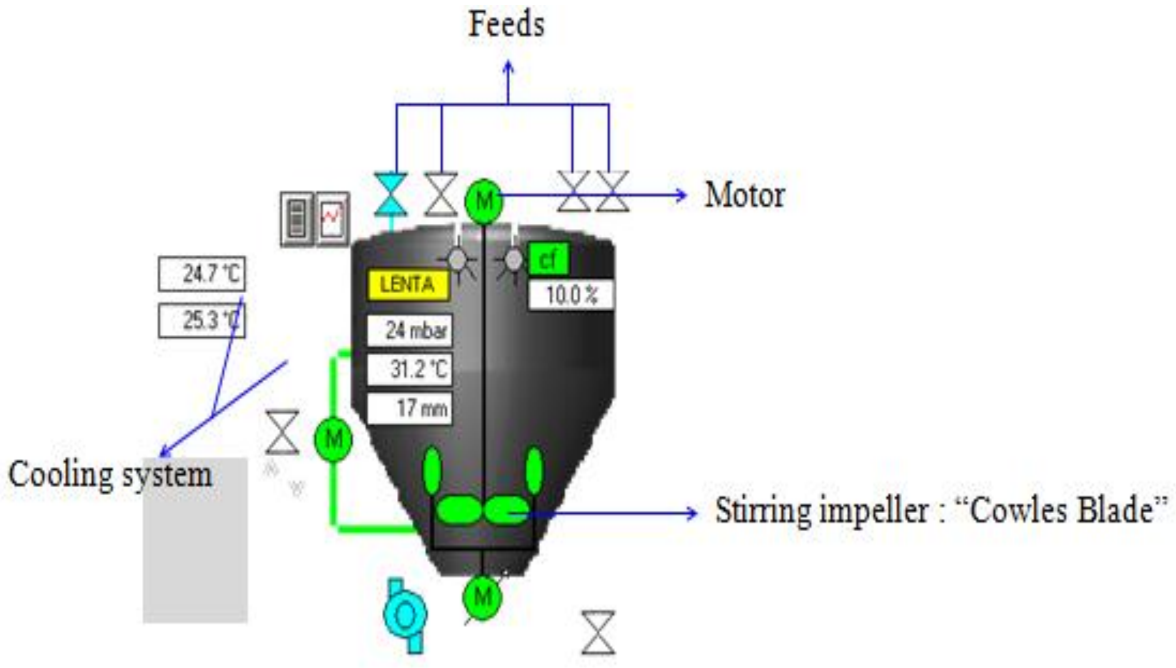


Figure 1-8 Automatic closed mixer

The stirring of vinyl-pastes has to guarantee high shear dispersion, in order to avoid formation of clumps and any kind of aggregates. This shear dispersion can be achieved by using a specific kind of stirring impeller, the so called Cowles Blade .

It is a dispersion blade with a rugged design, which has a combination of high spread dispersion capacity and pumping action in order to create a "spiral" effect in the middle of the mixer. This effect prevents sedimentation on the bottom of the mixer.

Because of the high speed of the blade, the temperature of the vinyl-paste rises. In order to preserve the quality of the produced pastes, the temperature has to be maintained under 40ºC. Therefore the mixer is provided with a cold water cooling device, that automatically keeps the temperature under this critical point.

For the case in analysis, the vinyl-paste production occurs in two automatic mixers. The two of those are called in this paper D_2 and D_1. The capacity of D_1 is comprised between a minimum of 1500 Kg and a maximum of 3300Kg. The capacity for D_2 is comprised between a minimum of 200 Kg and a maximum of 700 Kg. Vinyl-paste batches are either started on D_1 or D_2, according to the quantity of paste of each batch.

Figure 1-9 Cowles Blade

1.2.3.2 Mixer cleaning

The produced vinyl-paste references differ from each other in colour and in recipe. This brings the need for cleaning between batches. The cleaning process is done with industrial solvent – benzene derivatives – using specific washing programs controlled by computer. The prewashing is done with pre-used solvents while the final washing is performed with new solvents. After the final washing, the mixers are dried with vacuum. Because of the duration of the complete washing program, washings have to

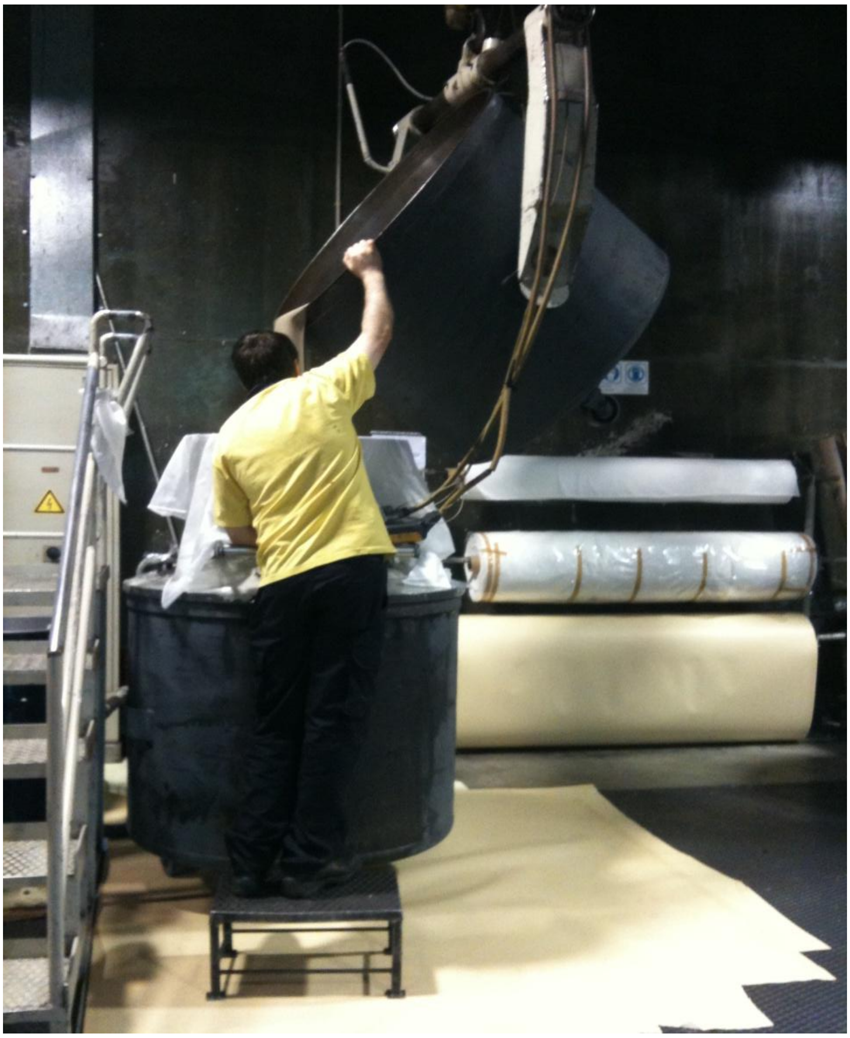
be kept in reduced number. A complete washing program lasts on average 75 minutes. This duration is even

longer than the time needed to produce some paste batches. Therefore the number of cleaning processes has to be minimised.

Vinyl-pastes can either be formulated to produce foamed foils or compact, monolithic foils. The first version, “foam-paste”, differs from the second one, mainly in the use of the so called foaming agents. These foaming agents are added to the pastes as additives. They act as nitrogen developing chemicals, once they are exposed to high temperatures like it happens during the coating process where the vinyl-pastes are spread-coated to form solid, flexible PVC foils. The use of blowing agents has absolutely to be avoided in compact-pastes. When there is the need to switch production from foam-pastes to compact-pastes, the mixer has to be cleaned.

Since vinyl-pastes are often pigmented, the transition between different colours has to be organized in a way that tries to avoid mixer cleanings as much as possible. Starting production with uncoloured or light coloured pastes and switching progressively to more dark colours, enables to minimize mixer cleaning.

1.2.3.3 Filtering process



Every vinyl-paste has to be filtered, in order to remove any dust or non-dissolved particles. A representation of filtering process is given in Figure 1-10 Filtering process.

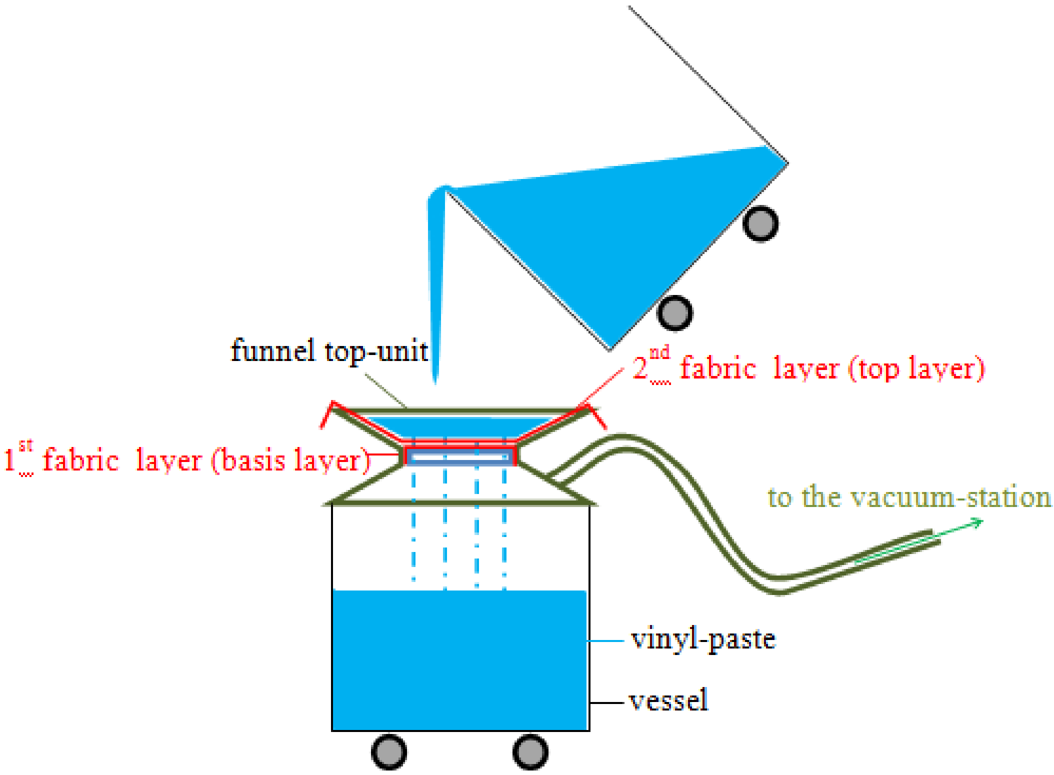


Figure 1-10 Filtering process

Filtering is a gravitational process, assisted with vacuum. In this process, the vinyl-paste is passed through two layers of a textile fabric, where not-solved and dust particles are stacked in the fabric mesh.

For this purpose, the vinyl-paste is transported to the filtering station, where a funnel top-unit is positioned over a cleaned vessel. The funnel top is prepared with the two textile fabric layers and connected to a vacuum pump. The vinyl-paste to filter, is transferred from its original vessel to the cleaned vessel covered with the filtration funnel. A schematic representation of filtering process is given in By combining gravity action with vacuum, the paste is sucked trough the textile fabrics where not-dispersed solid particles are caught by the textile net. Textile is changed when the reference of the paste change or when the textile net is saturated with solid particles.

1.2.3.4 Vacuum process

The last operation in analysis is the vacuum process. Here any air particle contained into the paste is removed in a vacuum chamber. The paste in its vessel is placed into a closed vacuum chamber, where a negative pressure of -1bar is applied for a certain amount of time. The duration of vacuum process is defined according to the plastisol recipe. Vacuum time between 15 minutes and 90 minutes are usually applied to the pastes. Air removal in plastisols is essential for the end-use of the final product – multi-layered flexible PVC foils.

During the vacuum process, the paste is slowly stirred, in order to facilitate the extraction of air. The stirring of the paste is done with a double pitched paddle impeller.

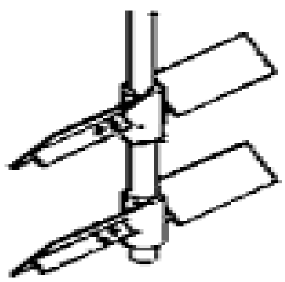


Figure 1-11 Double pitched paddle impeller

1.2.4 Applied industrial technologies for mass measurement

1.2.4.1 Strain gage load cells

PVC and all the used additives for plastisol formulations, even if liquid additives, are weighed with so called strain gage load cells. This kind of measurement technique is considered to be one of the most reliable and accurate available.

A strain gage load cell is an electrically resistive wire element that changes resistance when the length of the wire element changes. The gage is bonded to a steel cylinder that will shorten when compressed or lengthen when stretched. Because the gage is bonded to the cylinder, the length of the wire will lengthen or contract with the cylinder. The electrical resistance is proportional to the length of the wire element of the gage. By measuring the resistance of the strain gage, it is possible to determine the load on the load cell. The electric resistance is converted into mass unit readout by the electric circuitry in the readout device 0, 0.

These cells are used to sense the weight of the raw-materials in their respective scales. Each raw material has its own scale. Each scale is provided with three strain gage cells. The electric circuitry that controls the automatic mixers, converts the signal of the three cells into an unique value for the mass.

1.2.4.2 Volumetric pumps

To control the flow and the quantities of liquids used in higher amounts, like it is the case for the plasticizers, scales with load cells are not suitable anymore. High volumes and viscosities can easier be controlled with volumetric pumps. In this case, oval wheel meters are used to control the quantities of plasticizer in the mixing process, combined to mechanical, electrical and electronic instrument transmitters, whose signals can be used for remote indication, flow measurements and mass control.

Oval wheel meters are typically direct positive-displacement volume meters. Their measuring element consists of a measurement chamber or “casing” containing two toothed precision oval wheels. When the plasticizer flows through the casing, the oval wheels are driven by the plasticizer and roll off around each other. This rotational movement allows a fixed quantity of liquid to pass through the chamber per revolution of the oval wheel pair. The number of

revolutions measures of the quantity of material which flows through. The rotational motion is converted to a pulse signal, which is converted into volume and finally into mass information, enabling the quantification of the transported plasticizer.

1.3 Problem definition

Industrial vinyl-paste production is a complex system, with many factors influencing the final quality of the pastes, as well as the produced quantities.
Special issues in the complexity of the paste production processes turn production planning difficult regarding the required amount of needed paste in order to cope with the demand of finished goods.
This planning often can't determine successfully the right amount of paste to produce because of losses and deviations in the produced vinyl-pastes.

The vinyl-paste losses have to be analyzed and assessed through the whole production process in order to calculate time to time, the right amount of paste to give in input to the line in order to synchronise the production with customer demand.

The present work focuses on the study of TMG's vinyl-paste production, later used to produce by spread-coating, flexible PVC-foils applied for automotive interior trims.

The main problem of the Company is that losses of matter and general wastes all along the production line, cause difficulties in coping the demand of flexible foils by creating a deviation between required and real amount of vinyl-paste.

A certain amount of meters of foil is expected from a specific amount of kilos of paste, according to a receipt. The nominal quantity of raw materials calculated by following the receipt turns constantly out into a minor number of meters of finished foils. To solve this problem, the vinyl-paste production planning considers systematically a certain amount of paste extra in the receipt (e.g. 10% more). In other words, the production schedule is set up in order to cope with an extra-demand which should cover the losses of matter that seem to occur 99% of the times through the line.

Logistics is responsible for Sales, Distribution and Purchasing. The Production Department instead, is responsible for scheduling the production. It can choose the order of the batch to process, (e.g. all light pastes first) following the weekly MPS from Logistics.

The high variability that affect the production line and consequently the activity of production planning , cause many difficulties in any of the three core departments of the Company:

MAIN PROBLEMS

SD	PRODUCTION	PURCHAISING
• Inability to cope customers demand • Customers backorders • Reputation damage	• Managing the Rescheduling • Additional cleanings of the machines • Efficiency losses	• Urgent orders emission

1-1 Problematic

It is important to underline that all the bullet points written above are implicit consequences of the inability of the company to cope with the required amount of paste. In fact, losses of matter through the line do not represent itself a problem for the company. The main problems reported in the table, underline the implications of the gap between required and real amount of paste produced on how it affects operationally and economically the company.

Common and special causes are the main responsible for process variability. Common causes are purely random and intrinsically linked with the nature of the process. They are unidentifiable sources of variation. The special or assignable causes of variation, represent real process inefficiencies and are linked to factors that can be identified , minimized and in some cases eliminated.

Forecasting the processes capability in vinyl-paste production by identifying their statistical behavior, enables to optimize the effectiveness of the production line by providing to customers the right quantity of paste at the right time.

1.4 Literature contribution

Going through the literature shows that different methods for mass loss assessment can be taken into consideration.

The first method of our application is found in the Area of Waste Management. Due to the increased concern about the environmental consequences of waste and utilization, various models focus on identifying systematic trends and mechanisms that have been developed.

H. A. van der Sloot* [1] [2], shows that similarities in leaching behaviour occur throughout different classes of materials. For each material class, a limited number of constituents as well as parameters can be identified (e.g., pH, redox potential, complexation) as the key contaminants. The leaching behaviour of constituents has been assessed with several tests.

Jerzy Walendziewski* [3] analyses waste polymer cracking with two series of experiments. Under different experimental conditions we can draw on a range of conclusions.

This kind of examination falls in the vast analytical area of empirical methods [4], [5], [6]. The reliability of the results are limited due to the technique used to

collect the data. Using historical data instead of working with samples of cases, allows us to take into account a larger amount of results and to work with average values, by ensuring a lower data dispersion [7]. Marija Zupancic* [8] and D.S. Kosson [9] monitored the landfill leached for two years of time, in order to identify which parameters influence resituates concentration in soil. Similar studies about solid waste incineration residues have been carried out from T Sabbas, [10] and Amutha Rani [11]. Even if a large amount of data is collected, no coefficients are provided but positive or negative correlations. No mathematical model can be sorted out by this kind of studies [12], [13].

A review of the various waste management models has been summarised by A.J. Morrissey [14]. These models are usually used to support decision making in the area of municipal Waste Management and they take into account environmental, social and economical aspects.

Similar mathematical models to the one proposed in this paper, can be identified in many other different fields of research. Dushmanta Dutta [15] and A. H. Thieken [16] introduce an integrated model for flood loss estimation. The model is the combination of a physically based distributed hydrologic model and a distributed flood loss estimation model.

Hsiang-Ceiengk Ung [17], EJ Kansa [18], O Beaumont [19] elaborate a mathematical model for Wood Pyrolysis. The physical processes contained in the model include different variables (e.g variable density, specific heat, thermal conductivity).

G. B. Davis [20] develops a mathematical model to describe oxidation of pyritic material in mine waste. The comparison of the simpler model with the more realistic one is an interesting notion. It shows that for practical purposes a simpler model is good enough to assess the environmental impact of pollutant generation in the waste.

David Merrik [21] develops a series of mathematical models of coal carbonisation to assist studies of the coking process. Physical properties of coal during decomposition to coke are assessed. These models of physical properties may be found in more general application studies of coal-based processes [22] [23].

D. A. Haith [24] defines a mathematical model for the estimation of losses of dissolved and solid-phase pesticide in cropland runoff. This model is designed for use in water quality and pesticide screening studies [25] [26].

Another work of interest in the field of Medicine is proposed by Y. Smetannikov [27]. A mathematical model based on physiologic measures and describing the usual pattern of surgical blood loss is presented. It also addresses a theoretical means of minimizing intraoperative hemoglobin loss with hypervolemic hemodilution is proposed.

John D. Aber [28] predicted long-term patterns of mass loss, nitrogen dynamics, and soil organic matter formation from initial fine litter chemistry in temperate forest ecosystems. Three models were developed for describing change in mass remaining with time and for predicting weight losses accurately.

In the food industry, dry matter losses in corn mass production have been analysed by R.L.Pflugfelder [29] and weight losses have been assessed depending on corn composition. In the field of applied methodologies, Cousens, Roger [30] develops a simple model to describe crop yield loss as a function of weed density. The model, a rectangular hyperbola, has two meaningful parameters.

Despite the high complexity and accuracy, no methodology has been provided in order to achieve the various models described above. The conclusions made in these works show low enforceability, limited to their specific scientific fields of applicability. These models are not feasible for the PVC process in analysis and even though they may have similar characteristics with the model proposed in this paper; they do not include a methodology that can fit for similar processes.

1.5 Motivation for the project

The present work aims to lead to a mathematical model that considers all the main variables involved in vinyl-paste production processes which are responsible for deviations between theoretical required and real obtained amount of paste.

The goal of the project is to help the Company to cope with the required quantity of finish products, reducing the high variability that affect those processes and synchronising the production with the customer demand.

Furthermore it will lead to further suggestions (e.g. new technical solutions) that will increase the efficiency of the production line in analysis.

The model presented with this work has been developed for a specific vinyl-paste production of TMG Automotive. In this particular case, chemical variables do not play a significant role in losses, as the process we are analysing is not a chemical one. Different variables are taken into consideration, like for instance equipment characteristics and weight control techniques. Cleaning practices and filtering processes are also considered to have an influence in the losses observed.

Unlike the previous studies within the literature of loss of mass assessment, this paper presents not only a model which will help to cope the required quantity of finished products for PVC paste production process, but also a general methodology to investigate special causes of losses feasible for different industries.

The project focuses on analyzing the production of **five different references** of PVC pastes and the model relates the properties of pastes or process with losses in terms of Kilos of material, in order to comply with the required amounts of plastisols.

This will enable the company to correct the quantity of raw materials in input, depending on the product to produce and the characteristics of the manufacturing process. Moreover, an analysis of the current processes is presented in order to investigate the causes of inefficiencies through the paste production process.

In addition, the following work will add knowledge in the field of material waste management for vinyl-paste production. Furthermore, it will provide a more general methodology to assess losses through a production line and it will be available for any other application in different industries, for any study with a similar purpose.

2 MATERIALS AND METHODS

2.1 Applied Methodology

A methodology to investigate losses through a production line has been developed. The

The methodology is schematically represented thanks to a flowchart in

Figure 2-1.

The methodology described below has been used either to assess the PVC production line from losses either to create the mathematical model which will help to cope with the required amount of paste.

Even if the methodology has been created on the specific issue in analysis, it can be considered as a general methodology that can be applied to different processes and industries.

In fact, it remains a general path to assess and investigate a production line and to approach and solve efficiency issues.

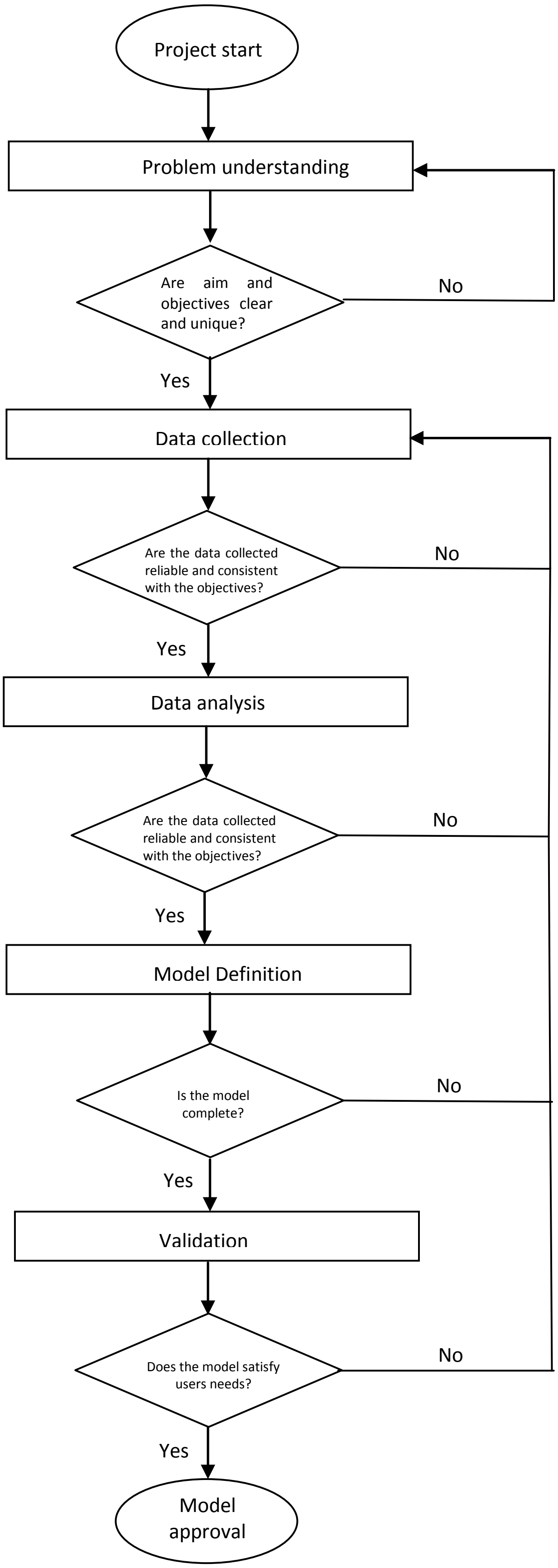

Project start
Problem understanding
Are aim and objectives clear and unique?
No
Yes
Data collection
Are the data collected reliable and consistent with the objectives?
No
Yes
Data analysis
Are the data collected reliable and consistent with the objectives?
No
Yes
Model Definition
Is the model complete?
No
Yes
Validation
Does the model satisfy users needs?
No
Yes
Model approval

Figure 2-1 Methodology flow chart

2.1.1 Problem understanding

Aim, objectives, area of working and potential constraint have to be clear and unique for the people involved in the project. Effective communication process between responsible for project assignment and analyzers, turns out to be essential for the success of the project. Regular meeting has to be settled in advance.

In order to have a clear understanding of the scope of the project and about company issues related, an Agenda has been developed and agreed with the managers of TMG.

AGENDA:

1ST WEEK

The Agenda included three meetings in the first week of the project, in which the following points were settled and recorded:

- Starting problem
- Project scope
- Final Expectations
- Area of working
- Main constraints

In the case studied a specific area of action has been taken as constraint, the analysis is limited to three steps of PVC plastisol paste production process: mixing, filtering and vacuum process.

The objectives comprise:

- to identify where losses of matter occur through the line
- to assess the variables of the process that influence the losses
- to create a mathematical model
- to make suggestions to reduce inefficiencies

2nd WEEK – END OF THE PROJECT

Weekly meetings were scheduled regularly, in order to track project objectives and measure the results achieved.

Every meeting has been driven with Power Point presentations, in which scope of the projects, results and further development were presented.

2.1.2 Data collection

Data collection is the most important step in driving an accurate analysis of the current situation. It is necessary to create a check-list of the data needed for the analysis by matching the information already owned by the Company with the ones to collect personally.

Table 2-1 Data collection

	Data already owned by the company	Data to collect personally
1° STEP	Filter the information provided	Plan data collection process
2° STEP	Verify data reliability	Create check-lists and questionnaires
3° STEP	Convert and store the information in digital format	Gather information from the shop-floor

- Data already owned by the company:

1° STEP: the information has to be filtered by necessity. To avoid to "fall in love with data", the data to process need to be valid, consistent on what is required to be measured.

In the case in analysis, customers orders, production schedule and weight of the pastes have been analysed for two years of time. TMG logistics department owns the relative data in excel files form, therefore the files has been screened and filtered to extract only the necessary data.

2° STEP: any time the data are provided as "stated", their reliability has to be verified. Data credibility is necessary in order to trust the results of the analysis. In the case studied, the data (e.g. Excel sheets) have been extracted from the Internal Information System of the company. The way chosen to verify the reliability of the data, is to monitor personally whenever the real data match the data stored into the system.
Two weeks have been spent to verify data reliability, by double checking the weight of the pastes before and after the mixing process of 20 different batches. The difference between the weight registered from the scales and the weight stored in the informatics system gave us an index of data reliability. Example of table used for data reliability verification is shown in **Errore. L'origine riferimento non è stata trovata.**.

3° STEP: In order to process the data efficiently and fast, any paper format should be converted in Excel file whenever is possible. During the project it turns out that the staff from the production recorded the reference of the batched that are processed into a cleaned mixer. This useful information has always been recorded in form of paper, therefore manually each reference has been transferred on excel in order to manage and cross the data with the ones already owned in excel format.

- Data to collect personally:

Whenever the data needed are not already available, they have to be collected personally.

1° STEP: the first step is to organize data collection process. A criteria in the way of collecting the data has to be followed. In the case studied, the time consuming to reach the information has been respected. The first data collected are the most time consuming ones. The mixing process has been assessed for first, then filtering and vacuum process respectively.

2° STEP: create in advance check-lists, questionnaires and tables is the most effective way to collect all the data needed. In this way, no information or detail can be missed. An example of table used for filtration process is shown in6.1A.2.

3° STEP: last step concerns the implementation of the measures in the area analyzed. In case studied, the shop-floor has been assessed through observations and interviews on field.

The check-list has been used to assess the filtration process form losses of matter.

For each batch wastes of materials has been measured by weighting the paste that remains stick into the internal walls of the vessel and over the different fabrics used for the filtration.

2.1.2.1 Data Collected

The data have been collected for the five references given from Logistics department (the pastes considered the ones with more losses and therefore the most critic “critic ones”).

Mixing process

To assess the mixing process from losses of matter the following data have been collected for the period of time between January 2012 till May 2013(current date when the analysis has been carried out):

- OE (batch reference)
- Paste reference (representing the type of paste)
- Mixer (type of mixer used “D1” or “D2”)
- Production date
- Required quantity ([kg] scheduled according to customer demand)
- Produced quantity ([kg] of paste actually produced)
- Total batch AZO (this is the quantity of paste [kg] that is actually given in input to the line form the system pumps-scales-mixers ruled by the so called AZO system *)
- Process deviation % (Difference between Required quantity and total batch AZO)
- Real loss % (Difference between Total batch AZO and Produced quantity)

An example of the file utilised is given below.

	A	D	G	H	L	P	Q	R	S	T
1	OE	Mixer	Required Quant.	Produced Real	Production Date	Total Batch AZO	Process Deviation [kg	Process Deviation [%]	Real Loss [kg]	Real Loss [%]
2	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
3	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
4	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
5	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
6	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
7	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
8	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
9	145910	D1	2850	2812	1/2/2012 08.38.47 AM	2839,508	-10,492	-0,36814%	-27,508	-0,97824%
10	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
11	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
12	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
13	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
14	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
15	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
16	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
17	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
18	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%
19	145943	D1	2050	1958	1/2/2012 07.54.37 PM	2048,376	-1,624	-0,07922%	-90,376	-4,61573%

** AZO system rules the scales and the pumps that allow the raw materials to flow inside the two mixers. The difference between required quantity and the quantity that actually flows inside the mixers needs to be analysed separately and split from the real losses. In fact real losses are real losses of material (physical), that can occur inside the production line. The process deviation on the opposite, takes into account the error that AZO system can commit. In other words the difference between required amount of paste and total batch AZO represents AZO accuracy.*

The data have been processed thanks to dynamic tables, due to the large amount of data and the information have been filtered according to the scope of the project (therefore filtered for the five pastes in analysis).

The reliability of the data above, has been evaluated through several tests.

The reliability tests consist on checking if the data stored from the internal informational system of the company (the data that appear in the excel file) were accurate.

Therefore taking as samples the current days (the 2nd and 3rd week of May) the losses have been measured manually from the two scales systems present on the shop floor. Then those results have been compared with the results that the system store. The accuracy has been evaluated around 99%, then considered as acceptable.

Figure 2-2 Excel file sample utilised

Filtering Process

The data needed to assess the filtering process from wastes of material, were not available. The company measured such losses (for example the amount of paste that sticks into the layers of fabrics used to filter) just ones, couple of years ago.

The company measured an average loss of mass for any paste : 2kg.

Therefore the logistic department always considered in the final MPS, two kilos of paste more than customer requirements. This measure does not take into consideration the properties of the pastes. My model aims to differentiate from paste to paste the losses in filtering process in order to achieve a higher accuracy level.

The data needed for such analysis were therefore collected personally through the shop floor, using the checklists and questionnaires present in Appendix A.

The information collected can be summarised in the following points:

- Reference number
- Batch number

- Weight of Fabric [kg] before filtration
- Weight of Fabric [kg] after filtration
- Losses in the 1st layer (the layer on the top of the filtering units that is changed after each vessel filtered)*

- Losses of aste [kg] in the 2nd layer (the layer in the bottom of the filtering units that is changed after several filtration of pastes)

- Number of filtrations made with the same layer on the bottom

- Losses / batch

The Excel sheet used is represented below. It is shown only to have a better understanding of the data managed.

	A	B	C	D	E	F	G	H	I	J	K
1	Ref.	Batch N°	Paste/Batch	Fabric before	Fabric after	loss 1 layer	medie 1 layer	Losses in 2°layer	medie 2 layer	N° filtration	Losses/Batch
2	2PLDB91701	155386		0,393	1,202	0,809	0,609	0,999	1,010	2	1,309
3	2PLDB91701	155387		0,393	1,180	0,787		0,999		2	1,287
4	2PLDB92743	155389		0,340	1,359	1,019		1,150		2	1,594
5	2PLDB92743	155390		0,340	1,237	0,897		1,150		2	1,472
6	2PLDB97481	155391		0,335	1,066	0,731		1,555		2	1,509
7	2PLDB97481	155391		0,335	1,020	0,685		1,555		2	1,463
8	2PADA97993	155421		0,215	0,590	0,375		1,344		5	0,644
9	2PADA97993	155421		0,227	0,611	0,384		1,344		5	0,653
10	2PADA97993	155421		0,250	0,592	0,342		1,344		5	0,611
11	2PADA97993	155421		0,220	0,577	0,357		1,344		5	0,626
12	2PADA97993	155421		0,216	0,531	0,315		1,344		5	0,584
13	2FAAR28802	155393		0,262	0,817	0,555	0,761	0,776	1,146	2	0,943
14	2FAAR28802	155393		0,262	0,947	0,685		0,776		2	1,073
15	2FAAV07992	155369		0,213	0,808	0,595		1,515		11	0,733
16	2FAAV07992	155369		0,213	0,907	0,694		1,515		11	0,832
17	2FAAV07992	155369		0,213	1,008	0,795		1,515		11	0,933
18	2FAAV07992	155369		0,213	1,130	0,917		1,515		11	1,055
19	2FAAV07992	155369		0,213	0,934	0,721		1,515		11	0,859
20	2FAAV07992	155370		0,213	1,011	0,798		1,515		11	0,936
21	2FAAV07992	155370		0,213	1,016	0,803		1,515		11	0,941
22	2FAAV07992	155370		0,213	1,036	0,823		1,515		11	0,961

Figure 2-3

Vacuum process

The losses and wastes in vacuum were usually considered in the 2kg of paste more with filtering wastes. In fact vacuum process as we will see below in more details does not represent a problem for the company, the losses usually amount to few grams per batch.

A more precise amount of losses has been evaluated during the project, the information collected were:

- Paste reference
- Weight of a perfectly clean fabric
- Weight of the same piece of fabric after vacuum process (the piece of fabric has been used to clean the impeller patch used in vacuum process, therefore to estimate the losses of paste) *

**The vacuum process as described does not include a change of vessel as it happens in filtering process. So the losses can be due only to the impeller that is used to mix the paste and consequently reduce the air particles*

N	O	P	Q	R
	REF	Fiber before	Fiber after	losses
VACUUM	2FAMA20799	0,22300	0,38700	0,16400
	2PADA97993	0,15300	0,23400	0,08100

Figure 2-4

Due to the small amount of pastes lost in this process, the data has been taken just for two main cluster of paste : the foam pastes and the compact pastes.

2.1.3 Data analysis

Before starting the analysis, a method to adopt in approaching the data analysis has to be identified.
There are many different approaches to elaborate and process the data.

One consists on elaborating data that have been collected personally. This method allows the researchers to get the right information they need, in real time, by directly taking them from the production line. This allows to get reliable data instantly, also consistent with the scope of the analysis.

The second method is based on processing historical data. This way of behaving could be seen as a slower and more complex way than the previous one. This method allows to work with a huge amount of data that are stored in the internal informatics system of the company. Using this approach can be tricky. It is crucial to keep in mind the meaning of the values and the purpose of the analysis. The criteria used for data analysis should be driven from the aim of the project .

In the case studied the both approaches have been implemented. In fact, the mixing process has been assessed from losses of matter by elaborating historical data from January 2012 until May 2013 thanks to the excel files provided by logistics department. This method allowed for example to set the coefficients of the model, by working with average values.

Never the less it required a verification process to test the reliability of the data available. The filtering and vacuum process have been analysed by collecting data personally, due to the non – availability of the data needed. In fact the logistic department had never assessed filtering and vacuum process from losses of material, therefore no data were available.

Mixing process

The data collected have been processed through the usage of dynamic tables.

Dynamic tables allows to identify trends or average values referring to the information of one year and a half. The output of such dynamic tables have been different graphs for each of the five paste reference in analysis.

The information that needed to be sorted by those graphs were:

1. Process deviation
2. Real deviation

Process deviation is reported in %. It represent the difference between the required amount of paste to produce (which correspond to the MPS produced from logistics) and the amount of paste that is given in input to the mixing units.

$$\boldsymbol{Process\ deviation}\ (\%) = \frac{\boldsymbol{Required\ quantity - AZO\ system\ batch}}{\boldsymbol{initial\ batch}}$$

2-1

It is necessary to underline again that the accuracy of AZO system needs to be separate from the real losses of mass that occur physically inside the line. In fact if the AZO system would work not-accurately, it should not figure into model.

The Real deviation is the difference between the quantity of paste that is given in input to the system through AZO and the amount of paste that actually comes out form the production process. This represents a real, physic, concrete loss of paste.

$$\boldsymbol{Real\ deviation}\ (\%) = \frac{\boldsymbol{AZOsystem\ batch - Produced\ quantity}}{\boldsymbol{initial\ batch}} \qquad \textbf{2-2}$$

These two percentages have been analysed for each paste reference and for each mixing unit (D1 or D2) , detailing the results for each batch during the period between January 2012 and May 2013.

Each graph of the so called “Bad cases” (the pastes that the Logistics department considered the most critical one sin terms of variability) is given in Appendix B.

In order to understand, how the other pastes behave in terms of variability, the logistics provided some “good pastes”, the references that in their opinion are affect from low variability. Therefore the difference between required and real amount of paste produced is low. The graphs with which I have been working are reported in Appendix B.

The results have been processes in order to extract from each paste and for each mixer the AVARAGE VALUE of losses occurred. A deeper explanation for the chosen method of working with average values is given below.

The results for each paste and mixer of the “bad cases” and good cases is given below

A	B	C	D	E
	2FABX00000		2FABG00000	
	Code	Material	Code	Material
	15100125	PVC VICIR E 1970 P	15100125	PVC VICIR E 1970 P
	15300015	Jayflex DIDP	15300086	Linplast 1012 BP
	15300086	Linplast 1012 BP	15400002	Estab Lastab CFL 202
	15400002	Estab Lastab CFL 202	15400031	Estab Lastab CF 375 T
	15400031	Estab Lastab CF 375 T	15901136	Ret Chama Óxido Antimónio N/3
	15600047	Carga Omycarb 5 Extra	5AG000150	Ag Exp Unicell D 300T 60:40 DIDP
	15901136	Ret Chama Óxido Antimónio N/3		
	5AG000150	Ag Exp Unicell D 300T 60:40 DIDP		
Mixer				
	Real Loss	Process Deviation	Real Loss	Process Deviation
D1	**-1,25%**	**-0,09%**	**-1,09%**	**0,11%**
D2	**-0,96%**	**0,08%**	**-1,35%**	**0,16%**
Diff	-0,29%	-0,17%	0,26%	-0,05%

F	G
2FBKF20799	
Code	Material
15100028	PVC LACOVYL PE 1311 H
15100079	PVC LACOVYL PB 1302 H
15300086	Linplast 1012 BP
15400002	Estab Lastab CFL 202
15400031	Estab Lastab CF 375 T
15901136	Ret Chama Óxido Antimónio N/3
5AG000150	Ag Exp Unicell D 300T 60:40 DIDP
5PG007100	PRETO PRINTEX V EM DIDP
Real Loss	Process Deviation
-0,37%	**-0,07%**
-1,05%	**-0,36%**
0,68%	0,29%

H	I	J	K
2FAMA20799		2PAAJ17986	
		Recepe	
Code	Material	Code	Material
15100125	PVC VICIR E 1970 P	15100125	PVC VICIR E 1970 P
15300015	Jayflex DIDP	15100133	PVC VICIR E 1271 P
15300086	Linplast 1012 BP	15300086	Linplast 1012 BP
15400002	Estab Lastab CFL 202	15400012	Estab Mark EZ 781
15400031	Estab Lastab CF 375 T	15400055	Óleo Soja ESO 260
15600047	Carga Omycarb 5 Extra	5PG001100	BRANCO 2220 EM DIDP
15901136	Ret Chama Óxido Antimónio N/3	5PG005150	AZUL CROMOPHTAL 4GNP EM DIDP
		5PG006150	VERDE HELIOGEN K8730 EM DIDP
		5PG007100	PRETO PRINTEX V EM DIDP
		Deviations	
Real Loss	Process Deviation	Real Loss	Process Deviation
-0,69%	**0,09%**	**-0,65%**	**0,19%**
-1,11%	**0,11%**	**-2,07%**	**-3,41%**
0,42%	-0,02%	1,42%	3,60%

L	M	N	O
2PLDB17936		2FAAR20799	
Code	Material	Code	Material
15100125	PVC VICIR E 1970 P	15100125	PVC VICIR E 1970 P
15100133	PVC VICIR E 1271 P	15100133	PVC VICIR E 1271 P
15300086	Linplast 1012 BP	15300086	Linplast 1012 BP
15400002	Estab Lastab CFL 202	15400002	Estab Lastab CFL 202
15400031	Estab Lastab CF 375 T	15400031	Estab Lastab CF 375 T
15400055	Óleo Soja ESO 260	15600047	Carga Omycarb 5 Extra
5DV000148	Lastab CF545 50 : 50 DIDP	15901136	Ret Chama Óxido Antimónio N/3
5PG001100	BRANCO 2220 EM DIDP	5AG000150	Ag Exp Unicell D 300T 60:40 DIDP
5PG007130	PRETO FW 200 EM DIDP	5PG007100	PRETO PRINTEX V EM DIDP
Real Loss	Process Deviation	Real Loss	Process Deviation
-0,64%	**-0,01%**	**-0,45%**	**0,00%**
-2,29%	**-0,52%**		
1,65%	0,50%		

P	Q	R	S
2EAAG20799		2PABA17993	
Code	Material	Code	Material
15100079	PVC LACOVYL PB 1302 H	15100079	PVC LACOVYL PB 1302 H
15100125	PVC VICIR E 1970 P	15100125	PVC VICIR E 1970 P
15300015	Jayflex DIDP	15300086	Linplast 1012 BP
15400082	Kicker Lankromark LZK 484	15400002	Estab Lastab CFL 202
15600047	Carga Omycarb 5 Extra	15400031	Estab Lastab CF 375 T
15901136	Ret Chama Óxido Antimónio N/3	15400055	Óleo Soja ESO 260
5AG000150	Ag Exp Unicell D 300T 60:40 DIDP	5PG007100	PRETO PRINTEX V EM DIDP
5PG007100	PRETO PRINTEX V EM DIDP		
Real Loss	Process Deviation	Real Loss	Process Deviation
-0,44%	**0,05%**	**-0,43%**	**0,02%**
-0,71%	**-0,03%**	**-1,20%**	**0,01%**
0,27%	0,08%	0,77%	0,02%

For each reference is also detailed the list of the raw materials used.

The values reported in the Excel sheet, has been used to assess the coefficients of the model in analysis as we can see in the next chapter.

A further explanation for the usage of average value is given in the paragraph 2.1.3.1.

Filtering & Vacuum process

The data from filtering process have been used to assess average values of losses for each foam and compact pastes. For filtering process having just two groups of pastes (foam and compact) has been considered an acceptable compromise between accuracy and effectiveness.

The data from vacuum process have been used to assess two average values of mass lost in vacuum process. One for foam pastes and on for compact pastes. As for filtering process, the accuracy of the measurement is considered acceptable in terms of project scope.

2.1.3.1 The averaged data approach

This paragraph aims to explain why data analysis is based on average values. Before starting the analysis, a method to adopt in approaching the problem has been identified.

There are different possibilities to assess the losses of matter along the line. The first and apparently the simplest one, would be to focus on the five paste references to analyze and follow, with personal data collection ,each production step in order to determine the factors that influence the losses. Since the time defined for the study was no longer then three months, the obtained amount of data would not be very high. During that period of time, each paste reference would be produced only between 10 and 20 times maximum. This direct approach would result in models with high intrinsic variability. In fact for one single paste reference, there are lot of possible variations in the production process characteristics that turns the dispersion of the results very high.

The only way to overcome a high variability is to work with a significantly high number of batches for each reference. This approach must rely on a data base where information are stored for a long period of time. Based on this, the analyzed information has to be treated statistically with average values.

Suppose for instance that another method is chosen, for example weighing personally the vessels in each step of the process before and after each operation. The results might be exactly the same. The advantage of working with averages is that the reliability of the results is higher, because no special (occasional) causes of variability could influence the results.

2.1.3.2 Losses vs Viscosity

One of the main suspects of Logistics department, was that the viscosity of the pastes plays a major role in mass losses.

The data about losses and the viscosity of the pastes processed have been analysed and crossed. The results proved that there is no a clear regular correlation between paste viscosity and loss of mass, as we can see form the Graph in Appendix C, Figure_Apx 12.

2.1.4 Model definition

2.1.4.1 Assumptions

1. The model investigates the behaviour of the process limited to the initial phase of coverings production: mixing, filtering and vacuum process.
2. This model can be applied only to PVC paste production and it is not valid for the remainder processes and products of the company in analysis.
3. Process deviation is considered 0% [1 2 3]
4. Pastes are considered as non-volatile

$$INPUT = N + \mathrm{N}\left\{\underbrace{D_1[a + P\ d] + D_2[b + P\ e]}_{Mixing} + \underbrace{f + \frac{ng}{700}}_{Filtering} + \underbrace{Fh + Ci}_{Vacuum}\right\}\% \quad [\mathrm{kg}] \tag{2-3}$$

2-1 Legenda 1

Processo	**Variabile inclusa**	**Valore variabile e Significato**
MIXING PROCESS	$D_1; D_2; P$	*D_1 ϵ {0,1} : D_1=1 se il mixer grande è in uso , 0 altrimenti*
		D_2 ϵ {0,1} : D_2=1 se il mixer piccolo è in uso , 0 altrimenti
		P ϵ {0,1} : P=1 se il mixer è utilizzato dopo il lavaggio , 0 altrimenti
FILTERING PROCESS	*n*	*Numero di filtraggi con stessa maglia inferiore : n ϵ Z+*
VACUUM PROCESS	*F;C*	*F ϵ {0,1} : F=1 se la pasta in analisi è spumosa, 0 altrimenti*
		C ϵ {0,1} : C=1 se la pasta in analisi è compatta, 0 altrimenti

[1] It is AZO system responsibility for deviation between nominal quantity and Input quantity to the mixer

[2] This does not represent a real loss of matter

[3] The average is 0% for any paste

Causes of wastes, variables responsible and coefficients have to be assessed in order to build the model.

The model includes variables that influence losses of matter through the line. These characteristics can be linked to properties of the process (e.g. temperature achieved, pressure, dimension of the surfaces involved…) or of the product itself (e.g. material volatility, paste viscosity…).

In the current study it is assumed that no leaks of material can occur because of the chemistry of the pastes. Parameters like volatility, room temperature or boiling temperature are not included into the model. In fact leaks due to either evaporation or chemical reactions, are considered as negligible.

In the model proposed the following variables are represented in 2-1 Legenda 1.

D_1 and D_2 refer to the type of mixer unit. Different sizes or shapes of the mixer, could influence the losses of matter. In fact the higher ratio (volume / internal surface) the lower the losses of mass. For mixing process, a third variable has been included, the one of cleaned or not cleaned mixer P. The production tries to avoid a high number of chemical cleanings. In fact a batch that is processed in a perfectly cleaned mixer will show a higher loss of matter.

Excel graphs used to assess losses due to mixer cleanings is shown in **Errore. L'origine riferimento non è stata trovata.**. One average value has been calculated for each one of the two mixers.

Regarding the coefficients, an analysis of the historical data has been carried out in order to identify for each paste the average loss.

The internal system of the Company, store data about nominal quantity (N), quantity in input to the mixer (I) and quantity in output from the mixer (O).

So $\Delta\ Real\ loss = O - I$ has been calculated for each paste and then an average value has been calculated for each paste and provided in form of coefficient.

The responsibility of clean or not clean mixer has been assessed by isolating the cases of clean mixer. The graphs used to assess the coefficient of clean and not clean mixer have been reported in Appendix B. The aim of those graphs was to identify whether the batches that are processed in a clean mixer present low losses of matter. And if yes, which is the percentage of mass lost per mixer.

Regarding the filtering process, the losses have been investigated by measuring the weight of the layers of fabrics used for filtering the paste. Again an average value has been calculated for each paste and taken as coefficient of the model.

Regarding vacuum process the losses have been measured by weighting the paste that sticks inside the vessel.

The results obtained showed that the loss of matter is really low, so this time, it has been decided to identify one coefficient for foam (F) pastes and another one for compact (C) pastes.

The different coefficients are provided in

Table 2-2. They have been identified for any of the five pastes in analysis. The coefficients derivate from different behaviour depending on the physical characteristics of each paste.

Table 2-2 Legend 2

Coefficients	Paste 1	Paste 2	Paste 3	Paste 4	Paste 5
a	1,09	0,19	0,11	0,38	0,96
b	1,14	0,81	0,95	2,07	0,88
d	1,12	0,12	0,12	0,12	0,12
e	0,71	0,71	0,71	0,71	0,71
f	0,40	0,11	0,16	0,09	0,32
g	0,32	0,16	0,30	0,14	0,27
h	0,02	0,02	0,02	0,02	0,02
i	0,01	0,01	0,01	0,01	0,01

2.1.5 Validation

Ones variables and coefficients are settled, a validation process is carried out in order to test the reliability of the model.

The validation needs to prove if the model matches user requirements by measuring the gap between the results observed and the ones predicted.

Whenever the validation does not identify a perfect match between real and modelled world, the gap needs to be analysed and compared with the needs of the users. In other words, the model aims to achieve the intended purpose even if the accuracy is not 100%.

One way of validating a mathematical model, is to run it for a certain number of times with different products.

The causes of variation in the results, are evaluated and analysed in order to improve the accuracy of the model until the necessary level.

In the case studied the validation has been carried out for three different pastes and three different shifts.

Table 2-3 has been used to assess the gap between real and predicted results of the model. As we can see, the nominal quantity is taken directly from the daily production schedule and it is compared first with the real amount of losses observed and then with the amount of losses predicted with the model.

Table 2-3 Example of validation table

Paste	Nominal Quantity (N) [Kg]	Real Quantity (R) [Kg]	Quantity predicted (Q) [Kg]	Real GAP = N – R (R_G) [Kg]	GAP predicted N – Q (G_P) [Kg]	Model Accuracy % (R_G-G_P) /N
1						

...						
N						

Model accuracy

The model has been validated through several runs on different pastes in different shifts.

The nominal quantity of paste in output from the process, that is planned according to the production scheduling, differ from the effective quantity produced (real gap). The model does not sufficiently cope with the amount of quantity lost in the process. The model gap is the projected amount of paste loss (kg) within the process. This differs from the real gap, indicating that the model is not 100% efficient.

Table 2-4 Validation in real case study

Paste	Nominal Quantity [Kg]	Real Quantity [Kg]	Real gap [Kg]	Model gap [Kg]
1	2500	2469	31	28.3
2	2600	2576	24	22.8
3	3250	3216	34	32.5

During my permanence in the Company, due to the large amount of time needed to validate the model, I have been able to observe the production results from three samples of the pastes needed. These samples represent just the first experiments on model accuracy, that have been increased and completed by the production crew over the last month and a half.

As it turns out from the results achieved, there is not a perfect match between the real gap and the gap predicted with the model.

According to validation results provided by the production team, the estimated error committed by the model is approximately + 1%. It means that the model estimates 1 % of paste more in input to the line than needed, on average.

This percentage has been estimated as an average value for different pastes.

The accuracy of the model is limited based on the two assumptions that have been made, which have taken into account in building the model:

1. Pastes in the analysed processes are non-volatile
2. Process deviation is considered 0%

These two main points will be described in more details in the discussions chapter.

3 LOSS SUMMARY

3.1 Loss responsibility for each process

Before settling parameters and coefficients to include into the model, an average losses value of any paste has been identified for each of the three processes in analysis.

It is interesting to notice the contribution that each process gives to the total loss rate. These values are shown in Table 3-1.

Table 3-1 Loss summary

Operation	Matter Loss per Vessel (700Kg)
Mixing	2.1%
Filtering	0.43%

Vacuum	0.022%

4 DISCUSSIONS

4.1 Model accuracy

4.1.1 Pastes in the analysed process are non-volatile

4.1.1.1 Principle of mass conservation applied to the mixing process

As already mentioned in previous chapters, the mixing process of a plastisol is not a chemical reaction. It's a physical stirring process in a semi-closed system, where energy exchange occurs. Rotational energy is applied to a solid-liquid phase, promoting dispersion and simultaneously friction between the different particles. This friction is partially converted into heat that is counterbalanced with water cooling in order to maintain the mixture temperature under critical 40ºC.

This mixing principle opens the way to a possible interaction between energy and matter. Since the mixer is a semi-closed system, such an interaction could theoretically lead to a loss of mass. A typical example of such a loss could be the evaporation of some components due to the action of heat. But in this case, evaporation is not possible. On one hand the heat peak is avoided by a water cooling system, which maintains the temperature in the mixer always under 40ºC. On the other hand, with temperatures under 40ºC, there is no possibility for evaporation since all the raw materials are not volatile under 80ºC.

Attending to this, the system can be treated like a closed system, where the mass must remain constant over time, as system mass cannot change quantity if it is not added or removed. Mass can neither be created nor destroyed, although it may be rearranged in space, or the entities associated with it may be changed in form, as for example when plasticizer molecules diffuses to the surface of PVC particles, surrounding them and keeping them separated from other PVC particles - dispersed. So the principle of conservation of mass, first outlined by Mikhail Lomonosov 0, can be applied to plastisols.

4.1.1.2 Low volatile loss values for plasticizers

Plasticizers play a central role in the formulation of plastisols. They are responsible for the flexibility of the final products and they are the second most important compound in the paste formulation, since they represent the second highest concentration after PVC itself.

PVC is not volatile at all and it starts to decompose itself thermally with temperatures above 180ºC. Plasticizers on the other hand are much more subjected to volatilization comparing to other liquid components of the plastisol.
Nevertheless plasticizers have low volatile loss values, like it can be seen in Table 2-4 [17].

Table 4-1 Plasticizer volatility

Plasticizer	DOP Di-Octyl Phthalate	DIDP Di-Iso-Decyl Phthalate	DINP Di-Iso-Nonyl Phthalate	2-Propylheptyl, Lauryl Phthalate	DBP Di-Butyl Phthalate
Volatile loss [wt %] *)	0.05	0.10	0.10	0.10	0.10 **)

*) test method: 130ºC for 3 hours

**) test method: 110ºC for 2 hours

An average volatile loss of 0.10 wt% for the most common used plasticizers, is very low and confirms the impossibility of loss of mass during the vinyl-paste mixing process, where temperature never rises over 40ºC.

4.1.2 Process deviation is considered 0%

Process deviation refers to the deviation between nominal quantity in input to the mixer which is required according to production scheduling and quantity of paste that effectively comes into the mixer. This deviation is due to the accuracy of AZO system, the one that rules the scales of raw materials and monitor the quantity of material in input to the mixer. Process deviation does not represent a real loss of matter. In fact this is just an information about the accuracy of AZO system and it does not influence the real loss of material inside the process.

The main reason of not taking it as a variable into the system is that the process deviation is around 0% on average for any paste.

As shown in **Errore. L'origine riferimento non è stata trovata.** (see the Appendix for any of the five pastes in analysis) AZO system works accurately. **Errore. L'origine riferimento non è stata trovata.** takes in example one of the five pastes analysed. The blue line indicates the so called process deviation and as we can see it is always surrounded by 0% for the both mixing units.

Nevertheless 0% is an average value. It means that the model cannot “feel” the variability of process deviation. This leads to a reduction in model accuracy.

4.2 Causes of losses of matter through the line

Once demonstrated that no losses of matter due to evaporation can occur through the three processes in analysis, the potential causes of losses of matter are the followings:

- Loss of mass during paste transfer operations
- Scales accuracy

4.2.1 Loss of mass during paste transfer operations

Now it's clear that the mixing process for a plastisol is a process where no loss of mass occurs regarding possible evaporations or chemical transformation into volatile compounds. But the mixing process is a batch process.
When the mixing process is completed, the paste has to be taken out of the mixer. Therefore it is logic to consider that some paste will remain on the internal walls of the mixer and on the stirring impeller. In order to minimize those losses, the automatic mixers are provided with an automatic scraper that collect and take out of the mixer the remaining paste.

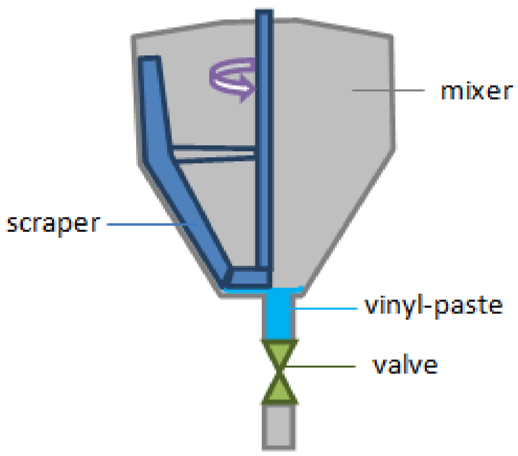


Figure 4-1 Mixing unit

The scraper is not able to collect 100% of the material remained.

Some paste will always be sticking to some surfaces and they should be considered as lost matter. Specially in the bottom zone of the mixer, in the out coming pipe, before the valve that lets the paste dropping out of the mixer, there is a certain volume of space where the scraper is not able to scrap the paste. In this zone the possibility for losses is much higher. Some paste always remains caught in this out coming zone. If the mixer is not cleaned after a batch, for the next coming batch, no more paste will accumulate in this zone. If this consideration would not be true, batch after batch, more and more paste would accumulate in the mixer. But due to the action of the scraper, this is not possible. Only small areas of mixer walls will be occupied by a limited amount of paste. After cleaning the mixer the paste will be removed from the out-coming pipe. According to this, it’s expectable that after a mixer cleaning process, the first batch that will be produced on that mixer, will show a higher loss of paste.

Filtering vinyl-pastes leads to loss of mass too, mainly due to the amount of plastisol that remains on the two textile fabrics used for filtering. Wherever the paste remains sticking to tools or recipients there is potentially a loss of mass. After filtration the used fabrics are full of paste . This is a clear and evident loss of mass Figure 4-3.

The same consideration has to be applied to the vacuum process, where some paste may remain sticking to the double pitched paddle impeller used in the vacuum chamber.

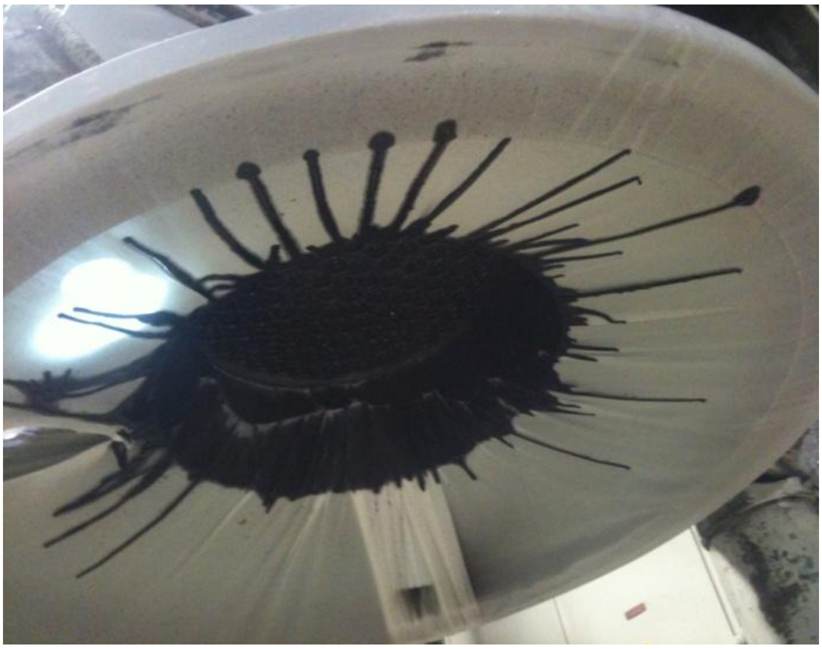


Figure 4-2 Losses in filtration process

Figure 4-3 Losses in filtration process

Figure 4-4 Losses into the vessel

4.2.2 General considerations about accuracy in mass measurements

Despite the relatively high accuracy of strain gage load cells, their use in an industrial environment can result in measurement deviations caused by vibrations. The main sources of vibrations are likely to be rotating machinery , like it is the case for the stirring mixers , and vibration from the floor, due to the heavy weight machinery used in the production line. This aspect has to be taken into account when analyzing the causes of deviations in the amount of produced pastes.

The same problematic of accuracy can be applied to the volumetric pumps. In this case the possible deviations of the measured mass, are not induced by vibrations but by small changes in the mechanics of the measurement system. Small changes of the plasticizer physical characteristics, like changes in density or in viscosity, can also lead to deviations. In fact those properties are directly used to convert the signals of the wheel meters into mass.

Therefore for the paste production process, the aim in weighing raw materials is not to achieve nominal weights but weights surrounding the nominal quantities asked in the recipes according to predefined tolerances.

5 RECOMMANDATIONS FOR THE COMPANY

5.1 Recommendations for improvements

With the purpose of improving production line performances and reducing inefficiencies, the following recommendations have been developed:

- Calibrate the scales regularly, prioritising the volumetric pumps
- Implement a new filtering concept, in order to eliminate the filtering process

5.1.1 New filtering concept

Although the filtering process is not the most critical one in terms of losses, the costs due to fibers, plastic and manpower are relatively high.

The new filtering concept proposed aims to eliminate the filtering process by filtering the paste directly into the mixers.
The new filtering system is shown in Figure 5-1 New filtering concept

The new filtering concept includes a new filtration system with two filtering units and one pump. The filtering units are used alternately to filter the paste output from the mixer. Each filtering unit is equipped with one nozzle that lets the paste enter through cladding where is filtered with a metal grid.
The system is quite simple, when one filtering unit is opened the other one is closed. The closed filtering unit can be taken off the pipe and cleaned. Two filtering units are needed because of the limited filtering surface compared to the one currently utilized.
A pump is needed in order to accelerate the filtration process.

Initial investment and cost saving have been evaluated and shown in Figure 5-2.

The costs have been provide from maintenance crew, who works closely with the production department.

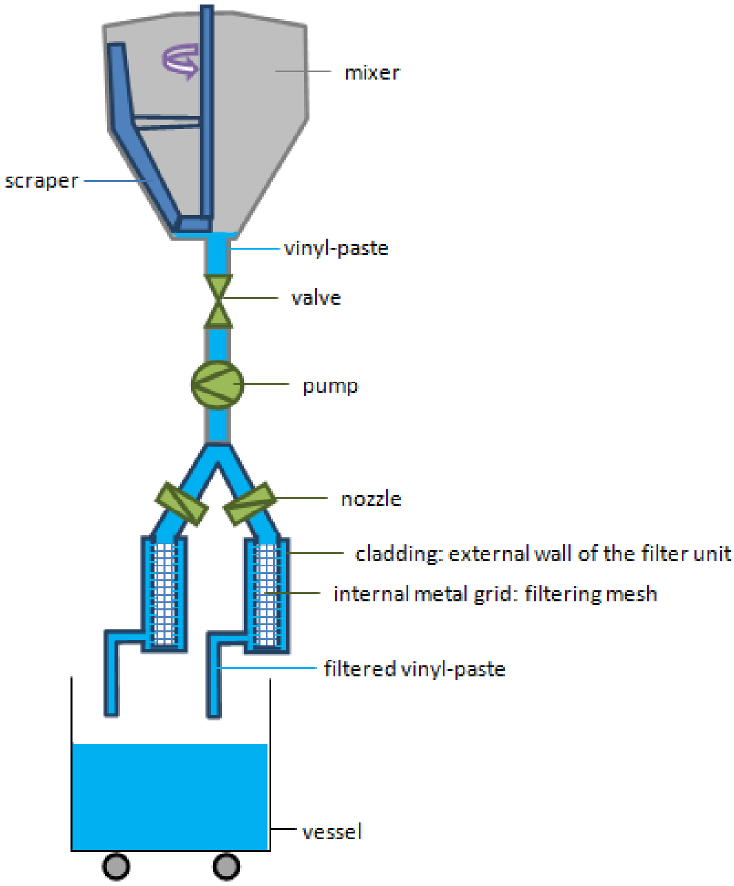


Figure 5-1 New filtering concept

Figure 5-2 Cost for the investment

Unit	Tot Costs [€]
Filtering Unit	2’000

Pump	2’500
Pipes & Labour	1’000

The costs for investment include the major costs involved in the new solution and consider the costs for the two filtering units, for the pump and the cost of the workforce needed to built the new system.

The cost savings are shown below, and basically they have been evaluated as percentages of the annual costs of three main used materials: solvents, textile fabric and polyethylene film. The usage of these materials in filtration process, has been used as driver to allocate the costs of the current filtration activity. Therefore these costs represent the cost savings with the new filtering system, and are differential costs.

Figure 5-3 Cost saving

Material	**Total Costs 2012 [€]**	**Total Costs 2012 [€] only for Filtration**	
Solvents	32 061.60 €	1/6 =	5 343.60 €
Textile Fabric	24 285.59 €	100% =	24 285.59 €
Polyethylene Film	4 109.16 €	1/2 =	2 054.58 €

In fact the energy consumption is more or less the same for the two solutions (vacuum pump vs diaphragm pump) and solvent consumption for cleaning of the new filtration units should be less important, less than 5000€. The main difference would be the cost reduction for labour due to the strong reduction in working hours with the new concept .

The cost savings reduction for the year are evaluated as 31.683,77€. Therefore around the 55% less than the costs of the actual filtering process.

6 CONCLUSIONS

6.1 Conclusions

The work presented enables us to describe the methodology used to investigate waste and losses of matter in plastisol PVC paste production, for a two tier supplier operating in the Automotive Industry.

The methodology applied, allowed to achieve two main objectives:

The first one is to identify where losses and waste of material occur through the production line and the possible causes related to them. Results regarding amount of losses have been investigated and estimated for any of the three processes in analysis: mixing, filtering and vacuum processes.

The mixing process has been identified as the most critical one, with 2.1% mass lost in one batch of 700Kg of paste. The mass loss within the filtering and vacuum processes are 0.43% and 0.022% respectively.
Loss of mass during paste transfer operations, problematic of mixer cleaning and scales accuracy have been identified as the main causes for material waste.

The second objective achieved is to develop a model which relates properties or characteristics of the process with losses of mass in Kilo units. The variables included in the model have been considered as the most significant ones regarding material wastage. The coefficients have been specifically addressed to the case in analysis and they are not feasible for any other company.

The model is based on two main assumptions :

- No evaporation of the paste can occur in the process during analysis
- Process deviation for which the AZO system is responsible is considered 0%

The method used to process the data collected is based on averages. This means that the coefficients are calculated based on average values taken from a period of time between January 2012 – May 2013.

The estimated error committed by the model is around + 1%. This is mainly due to the assumptions made, the accuracy of the scales and to the approach used to analyse the data which is based on average values. The accuracy has been verified through a validation process which counts on 21 different runs of the model within the daily production. The results have been identified for three of the five different pastes in analysis.

A literature review analysis shows that no similar models have been developed in order to assess and correct the gap between nominal and the real quantity of paste for PVC production.

The methodology itself counts five main steps. Although it has been applied directly on a real case study, it can be used in any other company that aim to assess and reduce waste of material through the production line. This methodology is feasible for different processes and industries.

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APPENDICES

Appendix A Materials

A.1 Historical data reliability

The following table has been used in order to measure the reliability of the data stored in the internal informatics system of the company.

Table A-1 historical data reliability verification

OE :

Ref:	Quantity:

Mixer clean : **Yes** ☐

Code	Raw material	Nominal weight (kg)	Real weight (kg)
	TOT. WEIGHT REGISTERED AFTER MIXER		
	REAL LOSS		

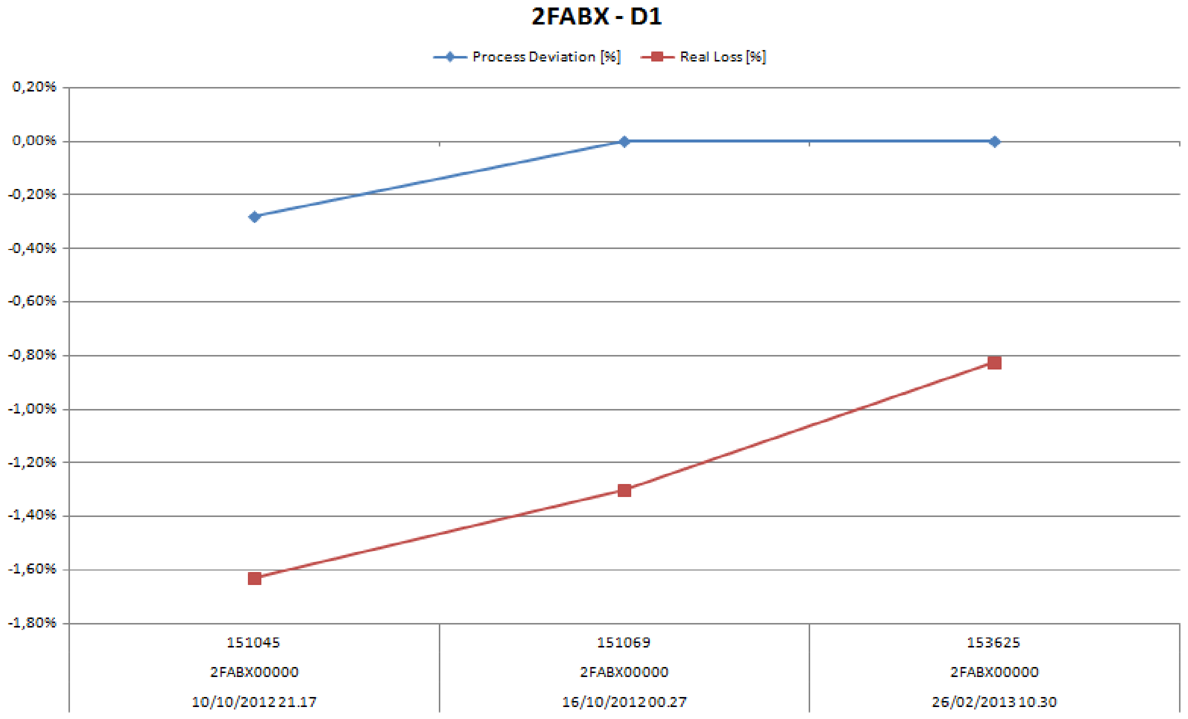
A.2 Loss assessment sheet filtering

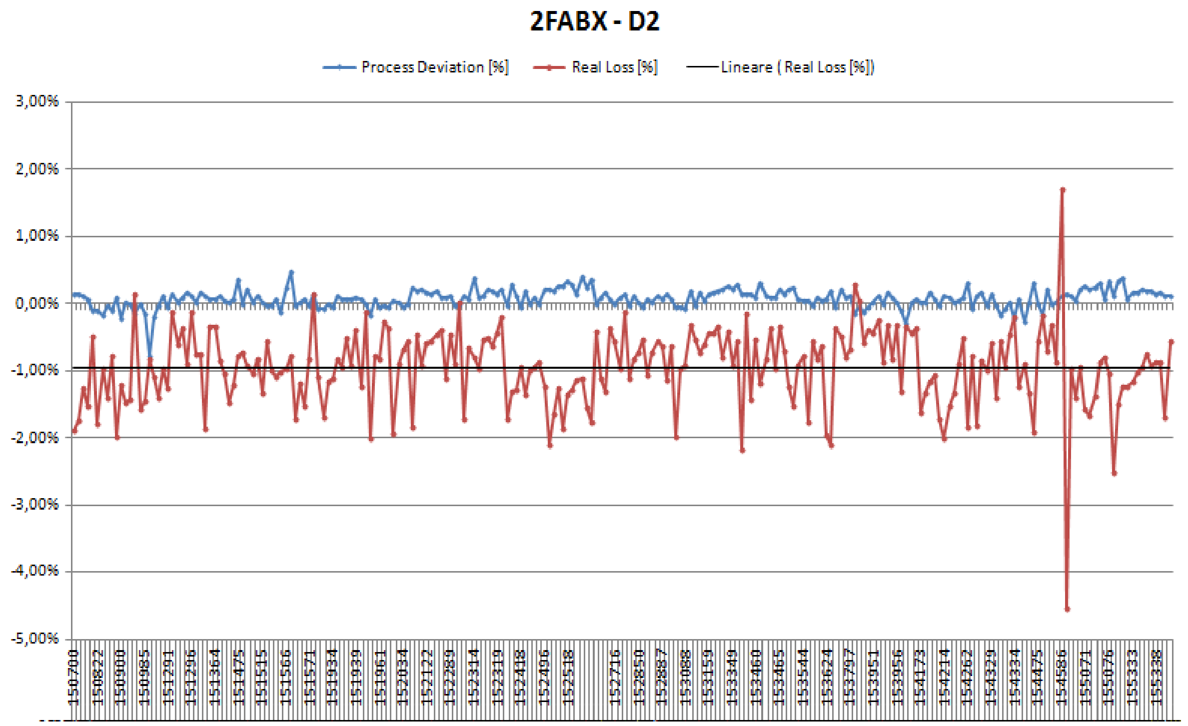
Table A-2 Loss assessment table

Batch N°	Weight before filtering [kg]	Weight after filtering [kg]	N° of filtrations	Observations

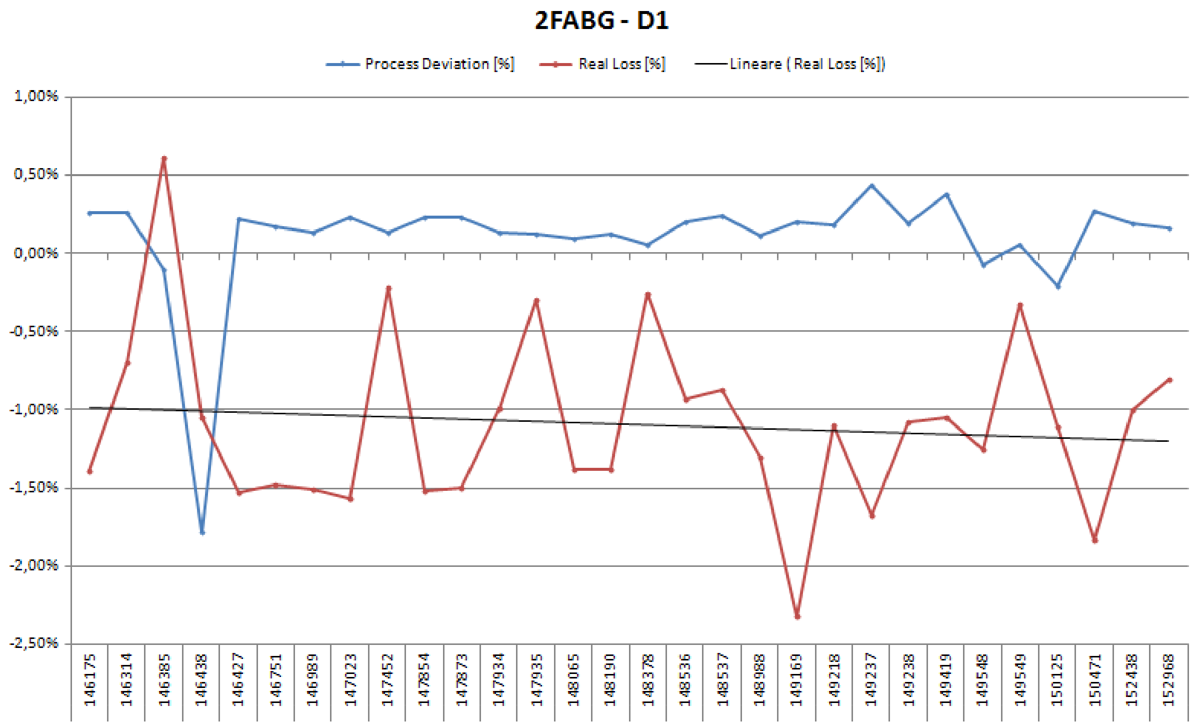
Appendix B Graphs for Losses

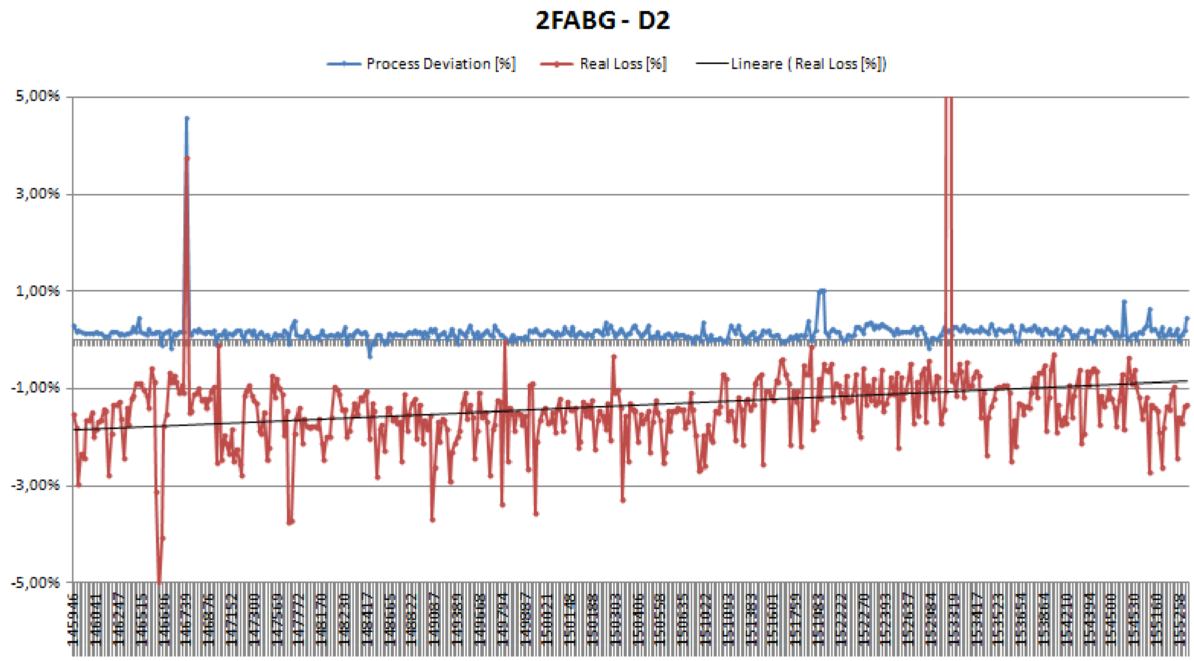
B.1 “Bad cases”



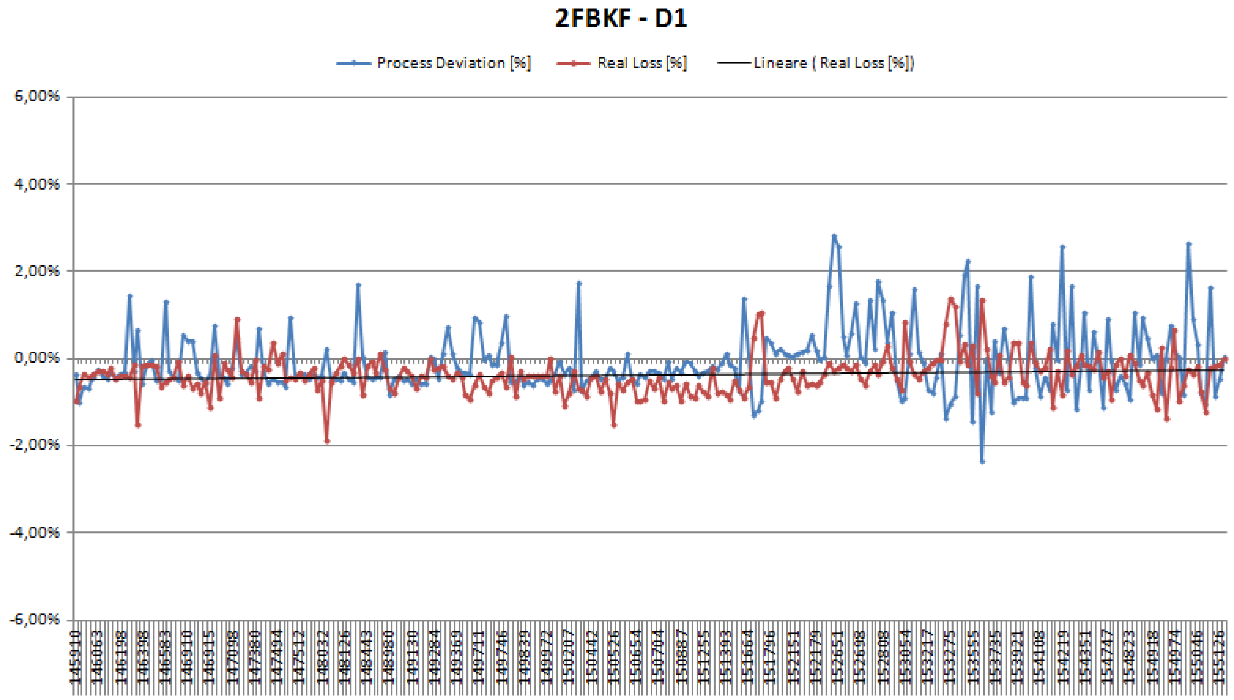


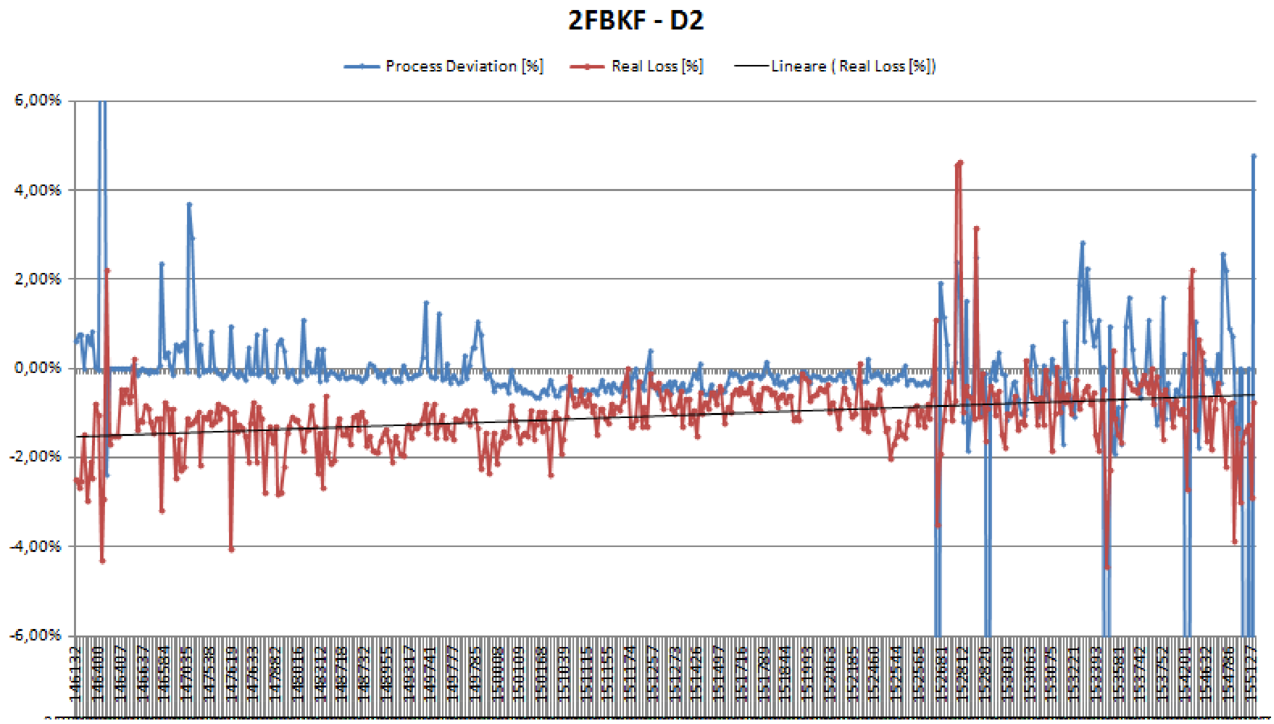
Figure_Apx 1 Ref Paste 2FABX, Mixer 1 an d2



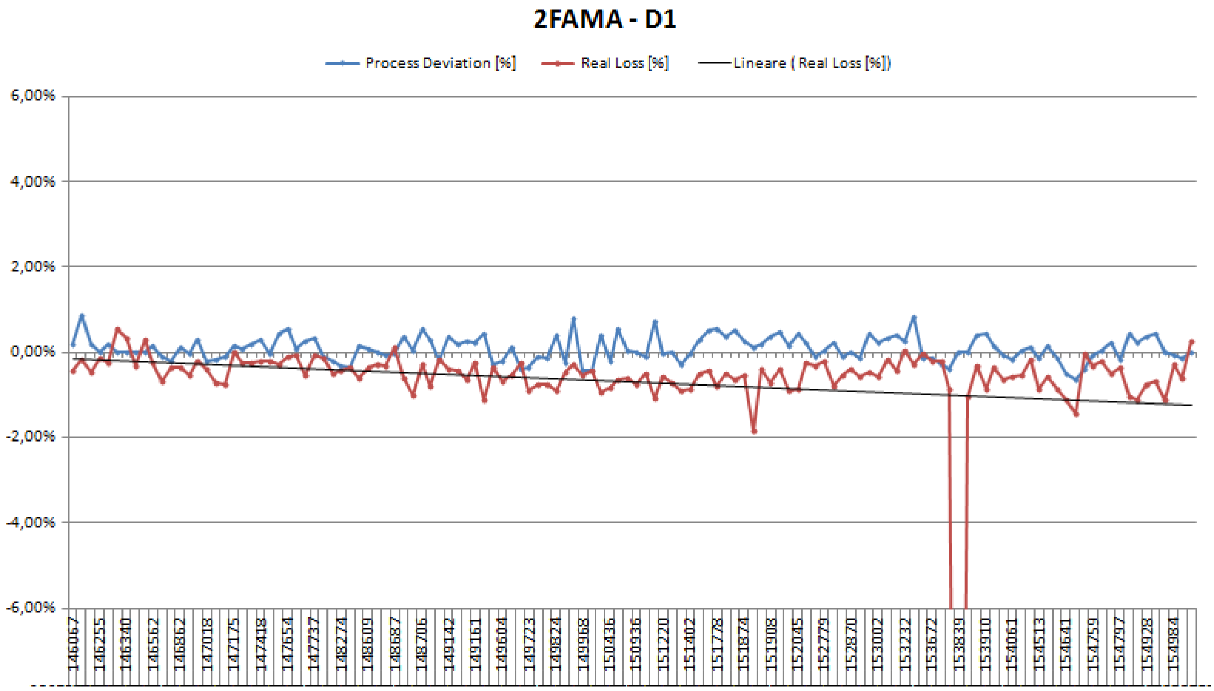


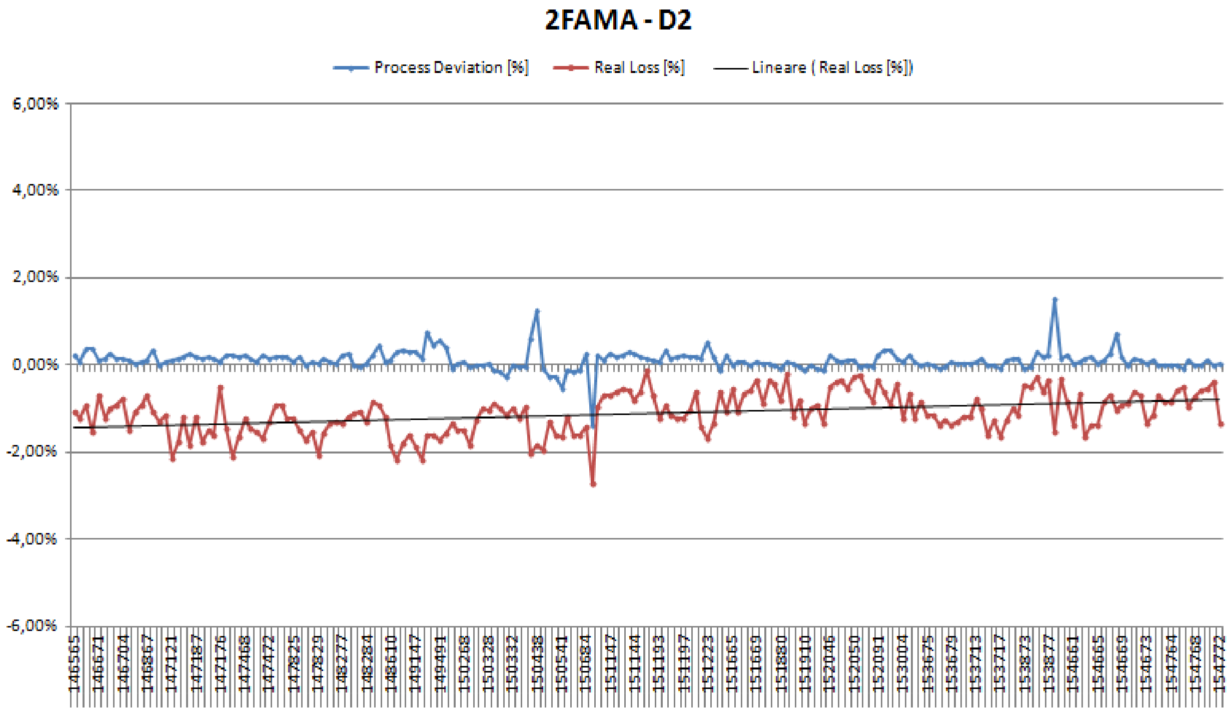
Figure_Apx 2 Ref Paste 2FABG , Mixer 1 and 2



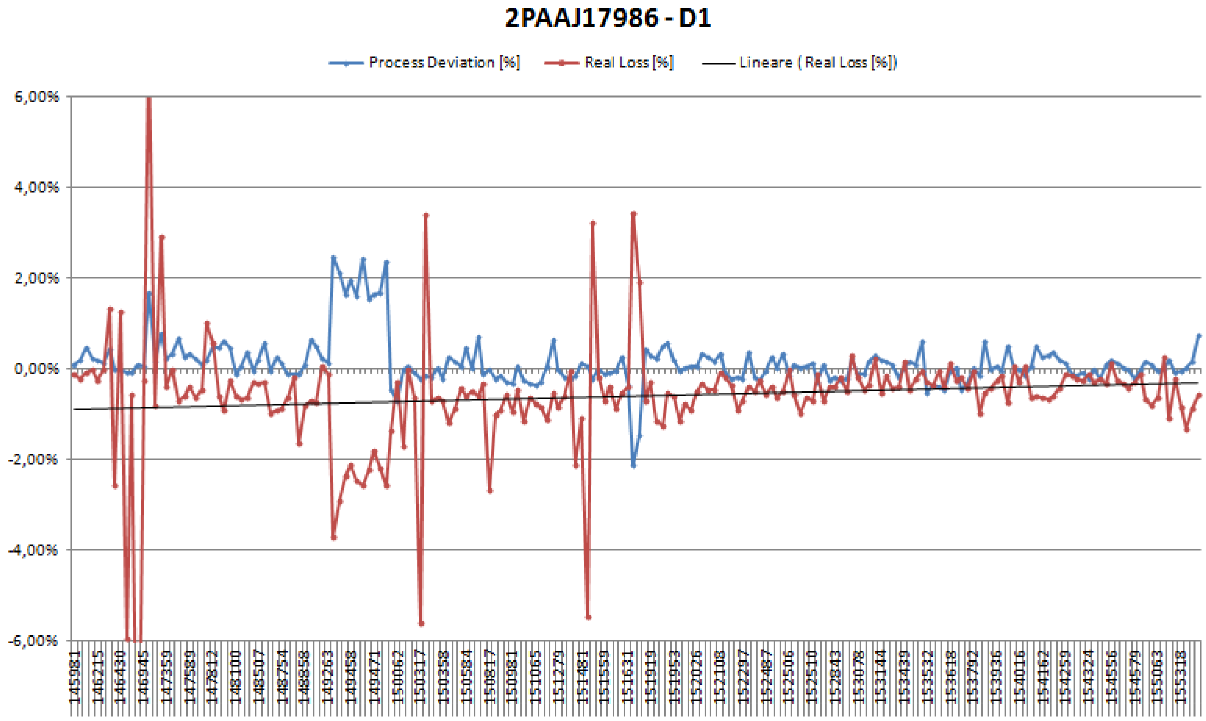


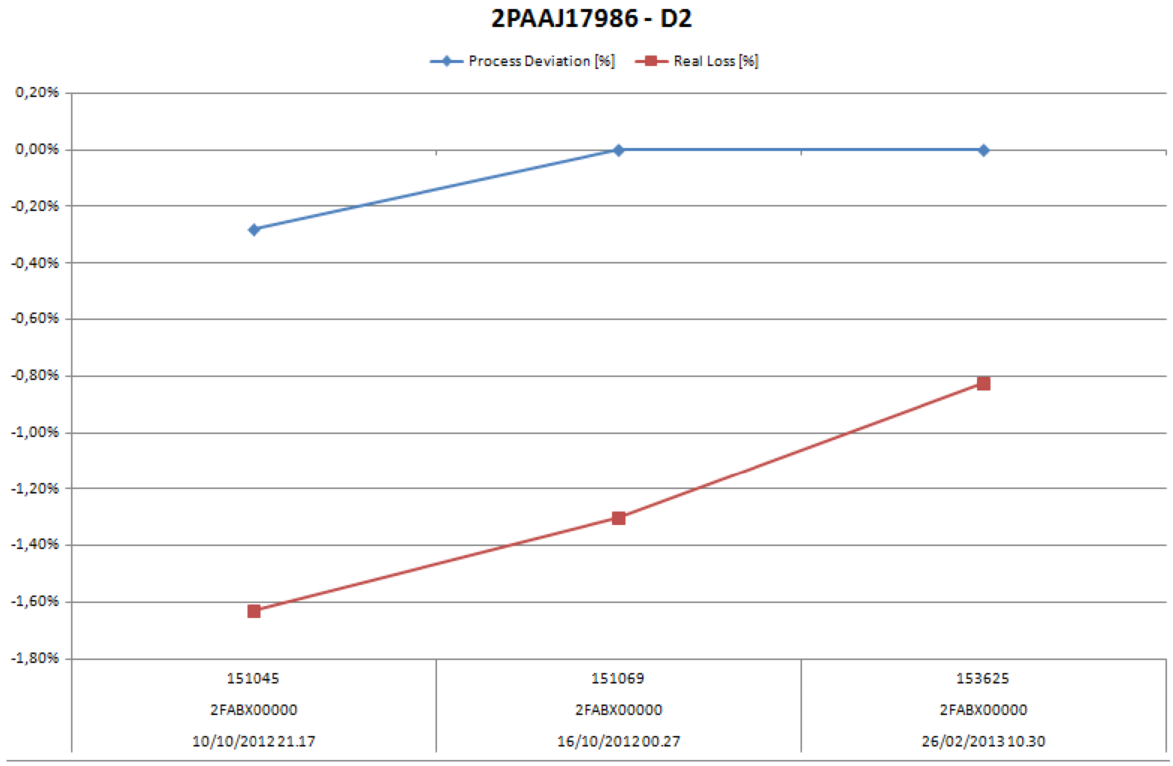
Figure_Apx 3 Ref Pase 2FBKF, Mixer 1 and 2





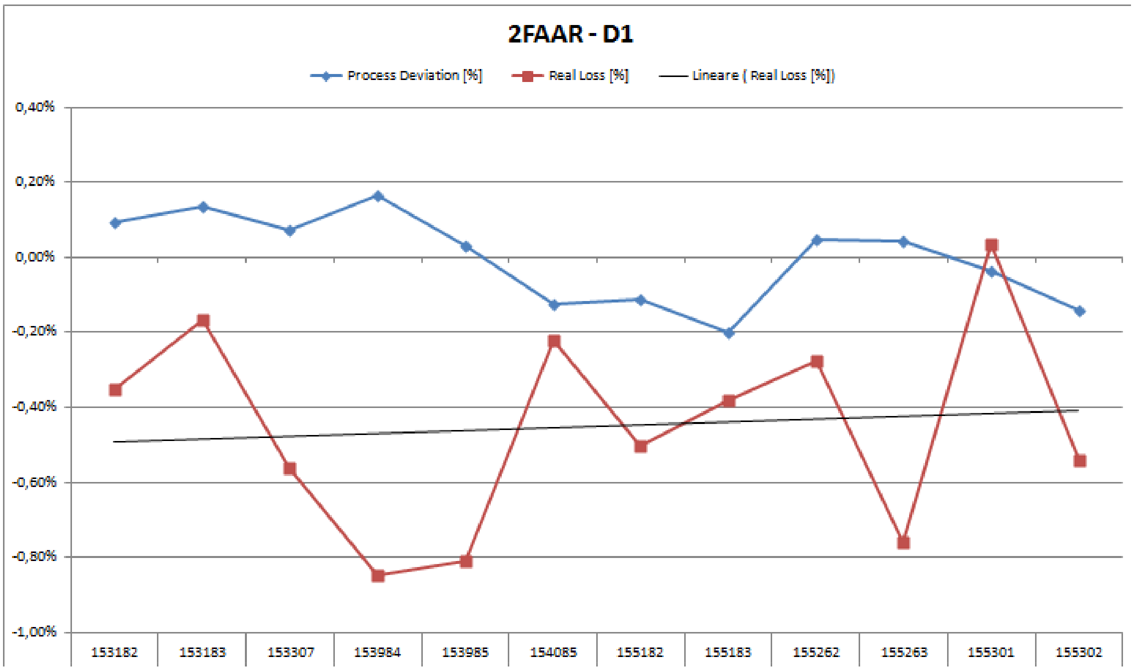
Figure_Apx 4 Ref Paste 2FAMA, Mixer 1 and 2

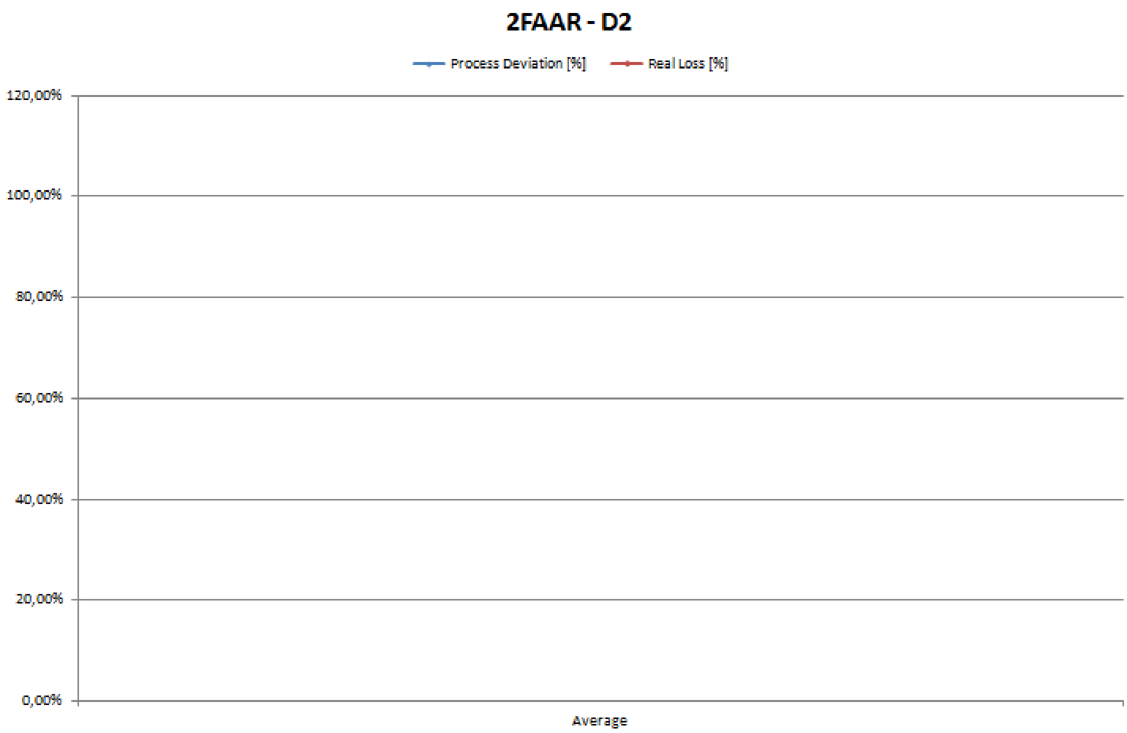




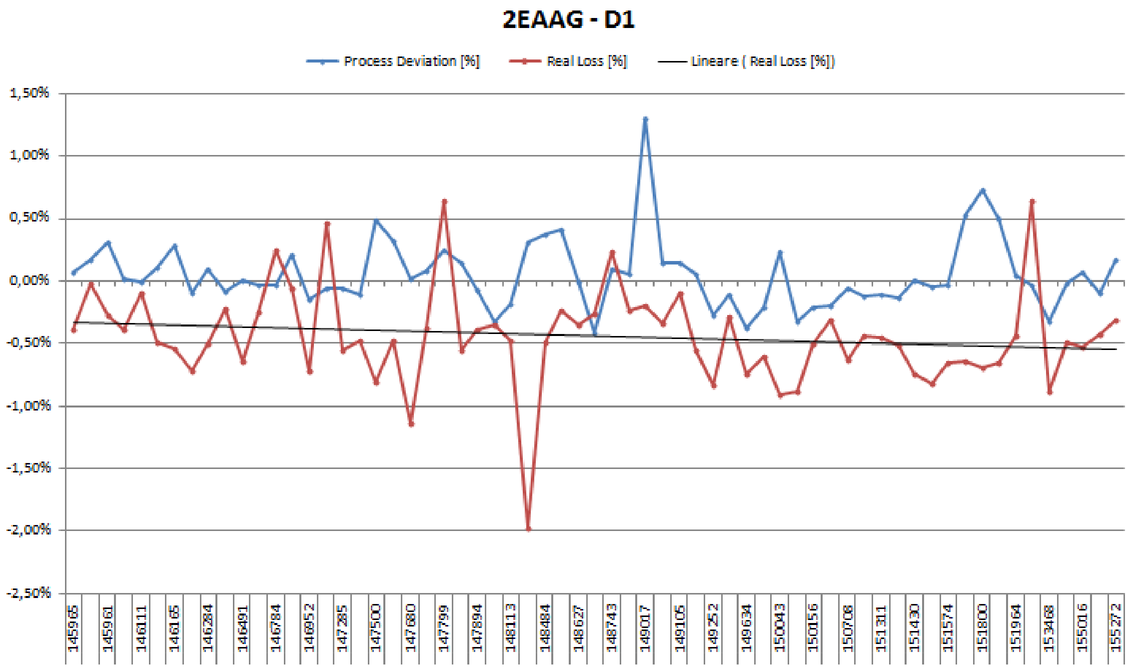
Figure_Apx 5 Ref Paste 2PAAJ17986, Mix 1 and

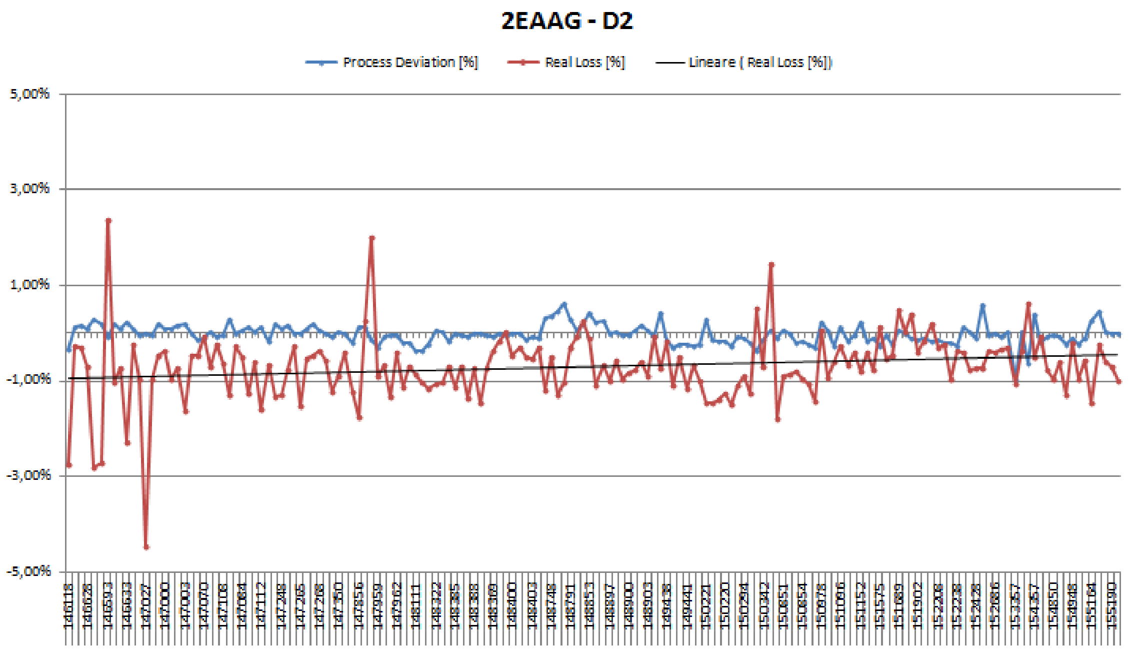
B.2 “Good” cases



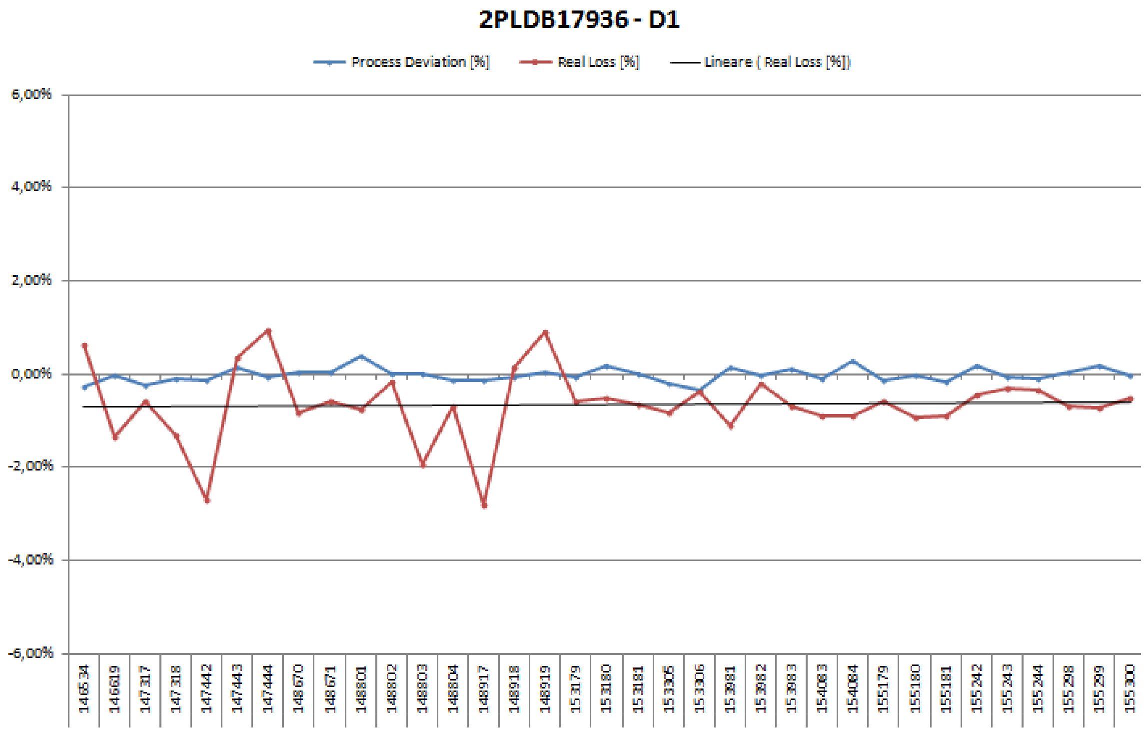


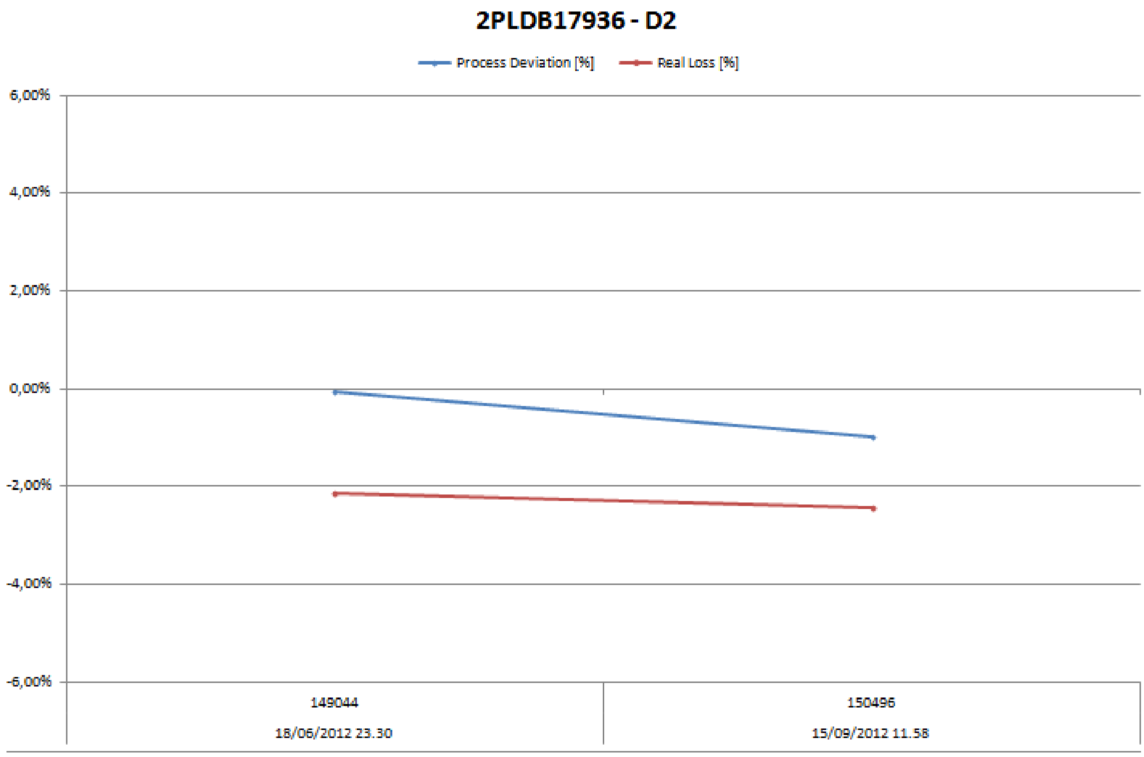
Figure_Apx 6 Ref Paste 2FAAR, Mixer 1 an d2



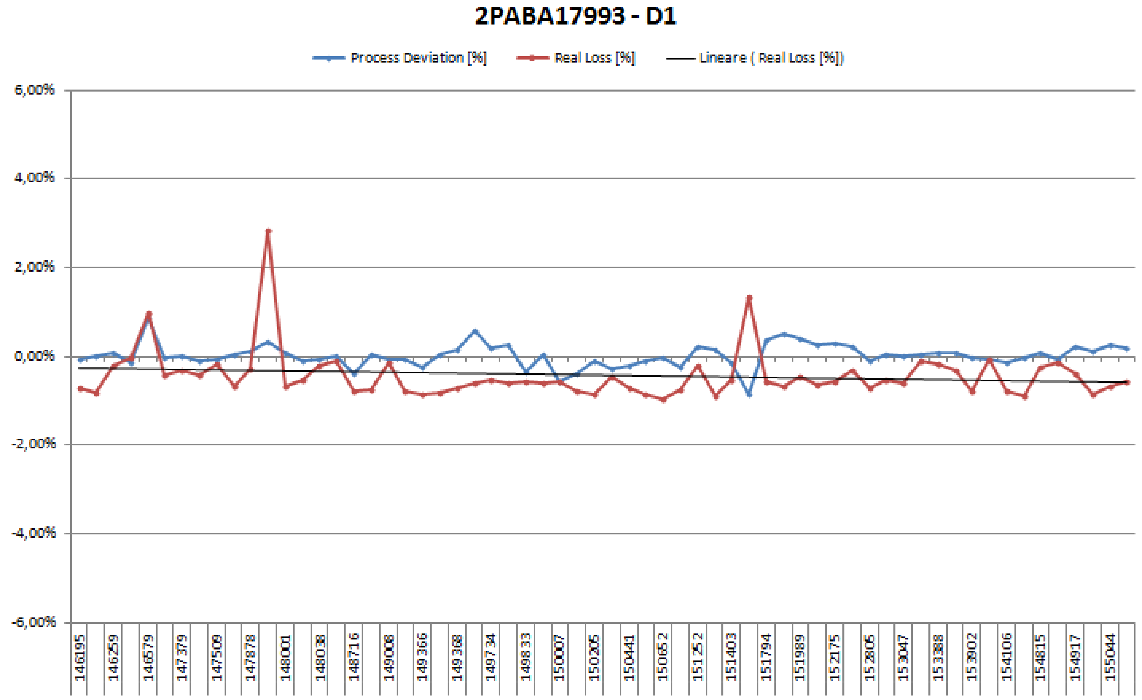


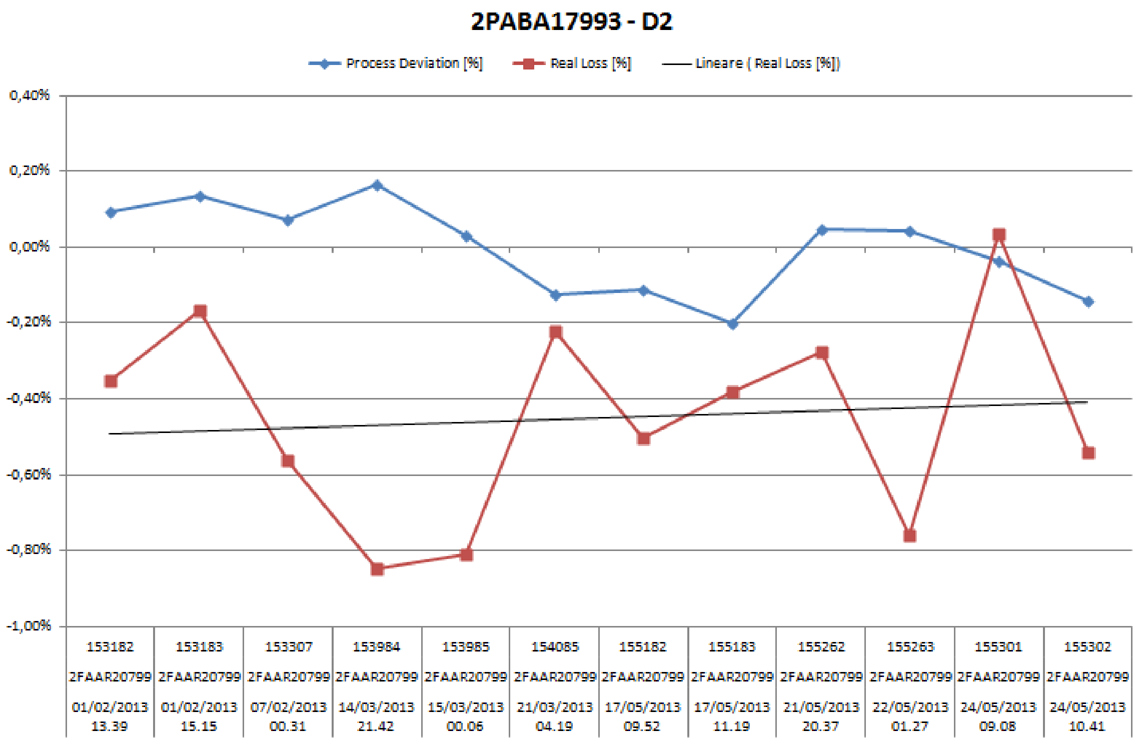
Figure_Apx 7 Ref Paste 2EAAG, Mixer 1 an d2





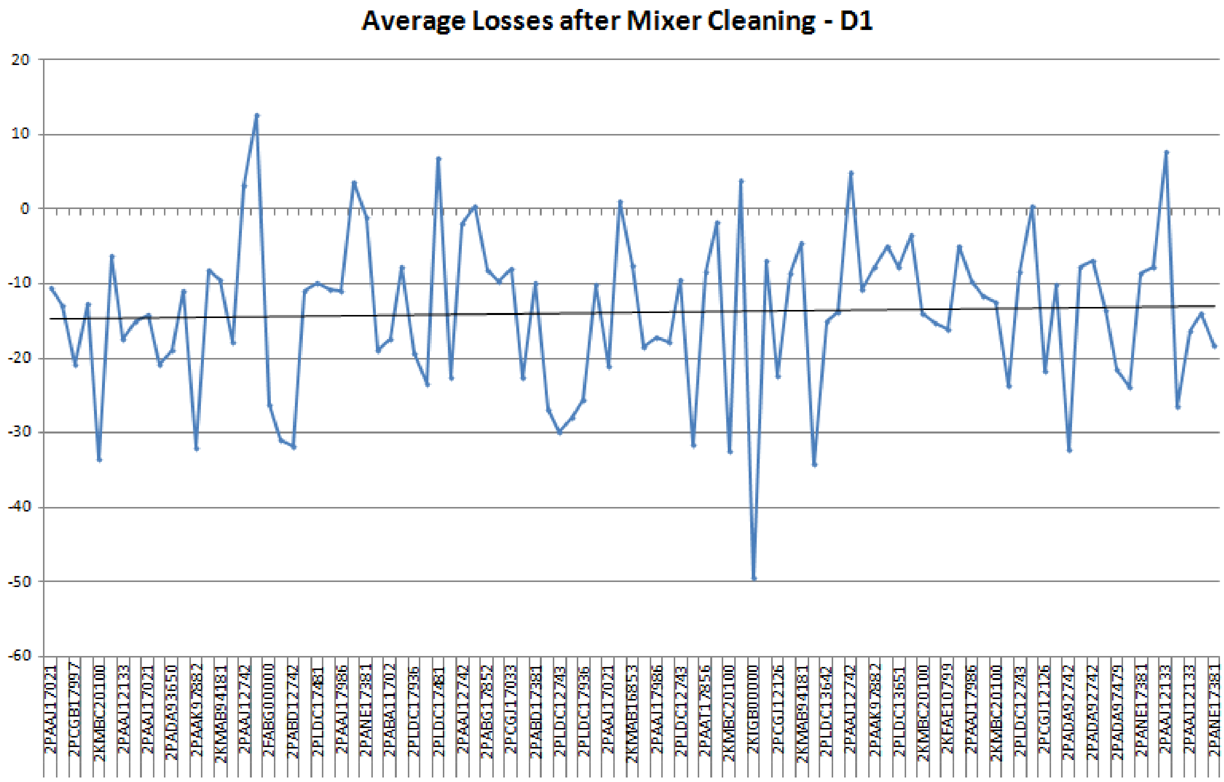
Figure_Apx 8 Ref Paste 2PLDB, Mixer 1 an d2





Figure_Apx 9 Ref Paste 2PABA, Mixer 1 an d2

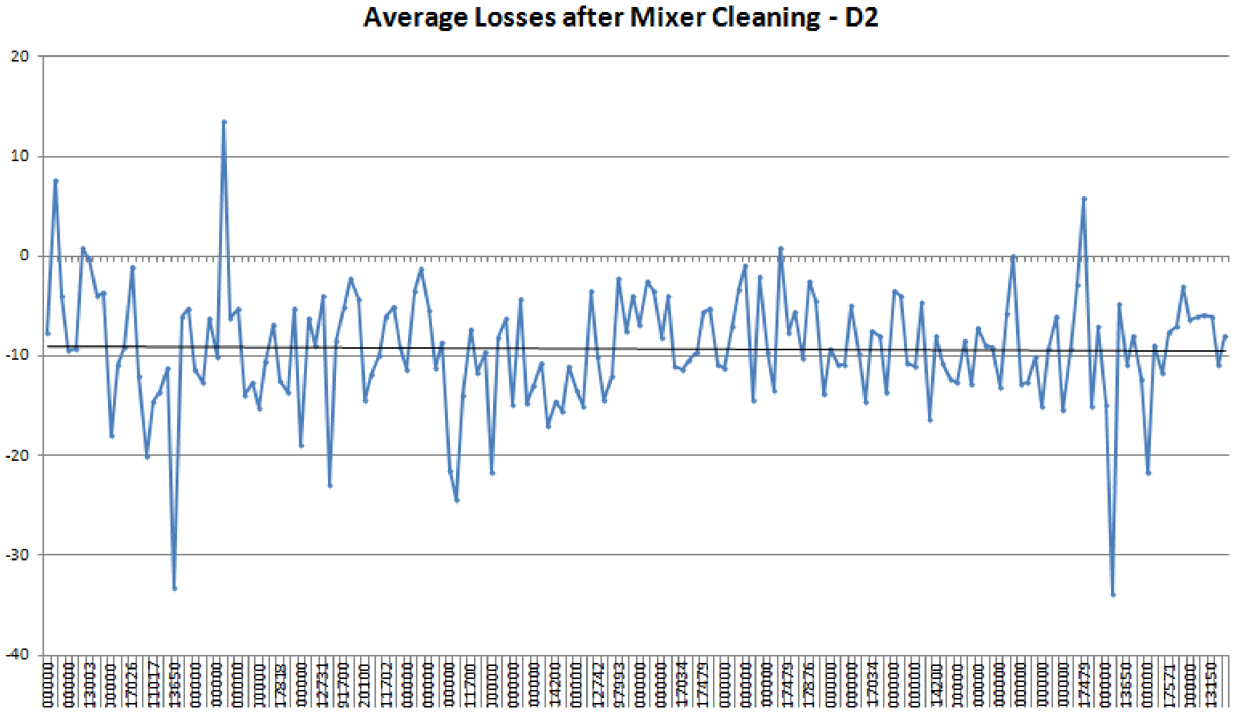
Appendix C



Figure_Apx 10

The y-axis is in kilos of paste. The x-axis represents the number of the batch in analysis.

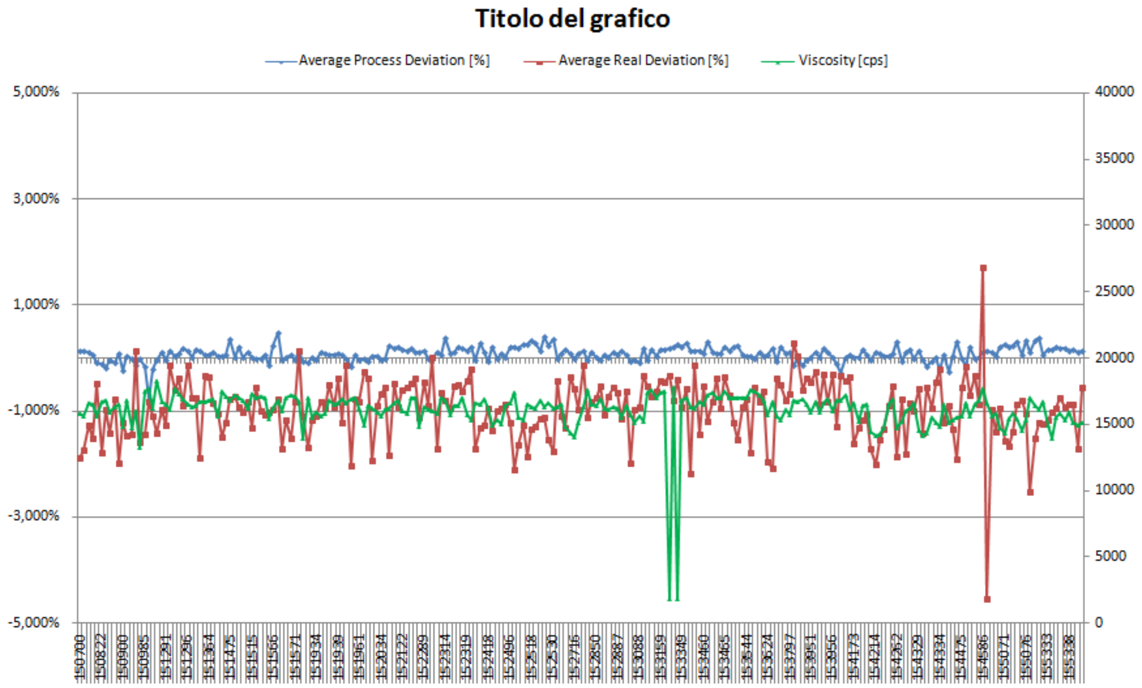
This graph is needed in order to find out the amount of paste (an avarage value) that is lost in Mixer 1, whenever the batch is processed in a cleaned mixer.



Figure_Apx 11

The y-axis is in kilos of paste. The x-axis represents the number of the batch in analysis.

This graph is needed in order to find out the amount of paste (an avarage value) that is lost in Mixer 2, whenever the batch is processed in a cleaned mixer.



Figure_Apx 12